STATE OF CALIFORNIA – CALIFORNIA NATURAL RESOURCES AGENCY

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JUN 11 2012

TO: Distribution List

The Department of Water Resources (DWR) respectfully submits a report required by section 10608.64 of the Water Code. This section is part of a water conservation law enacted November 2009 (Senate Bill X7-7, Steinberg).

Water Code section 10608.64 required DWR to report to the Legislature no later than December 31, 2011. The report, however, was delayed in order to develop methodologies and implementation plan with greater public acceptance.

The attached report describes the proposed methodology consisting of a tool box of methods and indicators for quantifying the efficiency of agricultural water use.

The methodology for quantifying the efficiency of agricultural water use described in the attached report has been developed through an extensive public participation process. It was a challenge to develop a methodology that satisfied the criteria prescribed in the law while taking into consideration the regional and local diversity of agricultural water supplier systems in California.

A summary of the report is also attached. If you have any questions or would like additional information, please call me at (916) 653-7007, or your staff may contact Manucher Alemi, Chief of DWR's Water Use and Efficiency Branch, at (916) 651-9662 or by e-mail at malemi@water.ca.gov.

Sincerely,

Mark W. Cowin
Director

Attachments

JUN 11 2012

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JUN 11 2012

A Summary of a Methodology for Quantifying

The Efficiency of Agricultural Water Use

Pursuant to Section 10608.64

The Water Conservation Act of 2009 (Senate Bill X7-7; Water Code §10608, et seq.) directs the Department of Water Resources (DWR), in consultation with the Agricultural Water Management Council, academic experts, and environmental stakeholders, to develop and report to the Legislature a proposed methodology for quantifying the efficiency of agricultural water use, as well as a plan of implementation including cost of implementation and the data needed to implement the methodology. The legislation did not authorize DWR to implement the methodology.

The methodology proposed in this report is composed of four consistent and practical methods for quantifying the efficiency of water use by irrigated agriculture. To develop the methods, DWR considered the components of a water balance at three spatial scales—basin, water supplier, and field—to understand and estimate through measurements or calculations how much water enters and leaves these areas. As a result, DWR proposed four methods for quantifying the efficiency of agricultural water use to help identify opportunities to improve the efficiency of water use at different spatial scales. The methods are fractions (ratios) that quantify the efficiency of agricultural water use by showing the portion of the applied water that was used for various intended uses—crop consumptive use, agronomic practices, and environmental uses. In addition to the four methods for quantifying the efficiency of agricultural water use, DWR has included in this report four indicators that would provide supplemental information about irrigation system performance and crop productivity.

The proposed methodology can be used as a tool to help evaluate current conditions and plan for strategies for improving agricultural water management. The anticipated users of these methods are farmers, water suppliers, and regional water management groups, as well as nongovernmental organizations and local, state, federal and tribal planners. The methods are not intended for non-irrigated agriculture such as dairy production areas, on-farm processing, or other agricultural operations not directly related to irrigated lands.

State of California
The Natural Resources Agency
DEPARTMENT OF WATER RESOURCES
Division of Statewide Integrated Water Management
Water Use and Efficiency Branch

A Proposed Methodology for Quantifying the Efficiency of Agricultural Water Use

A report to the Legislature pursuant to Section 10608.64 of the California Water Code

May 8, 2012

Edmund G. Brown Jr.
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State of California

John Laird
Secretary for Natural Resources
The Natural Resources Agency

Mark W. Cowin
Director
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and

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List of Acronyms

AU	agronomic use
ASC	Agricultural Stakeholders Committee
AW	applied water
AWc	applied water- county scale
AWf	applied water – field scale
AWMP	Agricultural Water Management Plan
AWb	applied water – basin scale
AWs	applied water – supplier scale
AWUF	agronomic water use fraction
CARCD	California Association of Resource Conservation Districts
CCUF	crop consumptive use fraction
CIMIS	California Irrigation Management Information System
CUP+	Consumptive Use Program+
CWC	California Water Code
CWP	California Water Plan (update)
CY	crop yield
DAU	detailed analysis unit
DF	delivery fraction
DU	distribution uniformity
DWR	California Department of Water Resources
ET	evapotranspiration
Etc	crop evapotranspiration
ETo	reference evapotranspiration
EU	environmental use
ETAW	Evapotranspiration of Applied Water
EWMP(s)	efficient water management practice(s)
FGD	farm gate deliveries
GCR	gross crop revenue
GW	groundwater
Kc	crop coefficient
M&I	Municipal and Industrial
PAW	productivity of applied water
Pe	effective precipitation
RF	recoverable flow
SB X7-7	Senate Bill X 7-7
SW	surface water
SWRCB	State Water Resources Control Board
TWS	total water supply
TWUF	total water use fraction
USBR	US Bureau of Reclamation
USDA-NRCS	US Department of Agriculture, Natural Resources Conservation Service
VAW	value of applied water
WS	water supplies
WMF	water management fraction

Executive Summary

The Water Conservation Act of 2009 (Senate Bill X7-7) directs the Department of Water Resources (DWR)—in consultation with the California Agricultural Water Management Council, academic experts, and other stakeholders—to develop and report to the Legislature a proposed methodology for quantifying the efficiency of agricultural water use and a plan of implementation that includes estimated implementation costs, roles and responsibilities, and types of data that would be needed to support the methodology. The legislation does not authorize DWR to implement the methodology. However, DWR recommends that if the proposed methodology is authorized for implementation, the Legislature should appropriate the necessary funding to cover its implementation costs as described in this report.

The Agricultural Stakeholder Committee was formed to advise DWR on implementation of the agricultural water conservation and planning provisions of SB X7-7.

To accomplish this and other provisions of SB X7-7, DWR convened an Agricultural Stakeholder Committee (ASC) consisting of agricultural water suppliers, academic experts, and environmental stakeholders to inform this work. DWR held numerous public listening sessions, stakeholder committee and subcommittee meetings, and public workshops to develop the methodology and prepare this report. During the process, numerous approaches and metrics were considered; and those that were not included in the proposed methodology are listed in Appendix E.

The proposed methodology is suitable to evaluate current conditions and strategies for improving agricultural water management on the diverse array of agricultural irrigation systems and operations found throughout California. The anticipated users of these methods are farmers, water suppliers, and basin water management groups, as well as nongovernmental organizations and local, State, federal, and tribal water planners. The methodology, however, is not intended for non-irrigated agriculture such as dairy production areas, on-farm processing, or other agricultural operations not directly related to irrigated lands.

The proposed methodology is suitable to evaluate current conditions and strategies for improving agricultural water management on the diverse array of agricultural irrigation systems and operations found throughout California.

Methodology for Quantifying the Efficiency of Agricultural Water Use

The methodology proposed in this report is composed of four consistent and practical methods for quantifying the efficiency of water use by irrigated agriculture. To develop the methods, DWR considered the components of a water balance at three spatial scales—basin, water supplier, and field—to understand and estimate through measurements or calculations how much water enters and leaves these areas. As a result, DWR proposes the following four methods for quantifying the efficiency of agricultural water use to help identify opportunities to improve the efficiency of water use at different spatial scales. The purpose, application, and implementation of these methods are summarized in Table ES-1 and Table ES-2 and described in Sections 3 and 4 of this report.

The methodology is composed of four methods for quantifying the efficiency of water use by irrigated agriculture.

- **Crop Consumptive Use Fraction (CCUF)**. This method evaluates the relationship (ratio) between the consumptive use of crop(s) and the quantity of water applied. CCUF is a fraction that shows the proportion of applied water that is consumed by the crop. It is applicable at the basin, water supplier, and field scales.
- **Agronomic Water Use Fraction (AWUF)**. This method calculates the ratio of agronomic use (salinity management, germination, etc.) and consumptive uses of crop(s) to the quantity of water applied. AWUF is a fraction that shows the portion of applied water used to grow the crop including crop consumptive use and agronomical use. It is applicable at the basin, water supplier, and field scales.
- **Total Water Use Fraction (TWUF)**. This method further expands on the CCUF and AWUF by evaluating the relationship (ratio) between water applied for crop consumptive use, crop agronomic use, and for environmental objectives and the quantity of applied water. TWUF accounts for all intended water uses; as a result, this fraction can be used as a measure of total water use efficiency. It is applicable at the basin, water supplier, and field scales.
- **Water Management Fraction (WMF)**. This method evaluates the relationship between crop consumption use and recoverable flows and quantity of applied water. This method estimates the recoverable water available for reuse at another place or time in the system. It is applicable at the basin and water supplier scales and is not intended for field scale.

Acronyms of four methods, each of which evaluates a portion (fraction) of applied water:

- *CCUF – crop consumptive use fraction*
- *AWUF – agronomic water use fraction*
- *TWUF – total water use fraction*
- *WMF – water management fraction*

The above methods are fractions (ratios) that quantify the efficiency of agricultural water use by showing the portion of the applied water that was used for various intended uses—crop consumptive use, agronomic practices, and environmental water. All of these fractions have values between 0 and 1. The greater the portion of applied water going to the intended uses, the larger the fraction, hence the higher the water use efficiency.

Plan of Implementation

The plan of implementation for the methodology presented in this report includes an approach, roles, implementing entities, data needs and sources, reporting, schedule/phasing, data management, and cost estimates that would be needed to implement the methodology (methods) proposed in this report for quantifying the efficiency of agricultural water use. The proposed implementation entities are shown in Table ES-1 and summary of implementation plan is shown in Table ES-2.

DWR recommends that if the proposed methodology is implemented, it be carried out using existing programs to the extent possible, and by expanding them, creating new programs, and/or reviving past programs as needed to avoid redundancy and reduce implementation costs. Existing legislation (CWC section

10608.48(d) and (h)) would provide a process for agricultural water suppliers to submit to DWR the results of quantification of efficiency of water use in their Agricultural Water Management Plans (AWMP). Agricultural water suppliers subject to CWC section 10826 (water suppliers greater than or equal to 25,000 acres and water suppliers less than 25,000 and more than 10,000 acres, if funding is available) would include in their AWMPs the results for the supplier basin scale methods (CCUF, AWUF, TWUF, and WMF), as well as the mean and standard deviation of the field scale values for CCUF, AWUF, and TWUF compiled voluntarily from their service areas.

Table ES-1 Proposed implementing entities

	Proposed implementing entities		
Water use efficiency quantification methods	Basin-alliance	Supplier	Voluntary irrigation system evaluation*
Crop consumptive use fraction (CCUF)	√	√	√
Agronomic water use fraction (AWUF)	√	√	√
Total water use fraction (TWUF)	√	√	√
Water management fraction (WMF)	√	√	--

*CWC Section 10608.48(c) requires that water suppliers equal or greater than 25,000 acres provide on-farm irrigation system evaluations for their customers. Although CWC does not define on-farm irrigation evaluation, the application of the three methods would evaluate irrigation systems.

Summary of Implementation Costs

The proposed plan of implementation would require new funding for DWR and water suppliers. These costs are summarized and described in Section 4.5.

DWR costs

The cost to DWR to support implementation of the proposed methodology is about $400,000 per year in addition to a one time cost of $500,000 for developing a database.

Costs to water suppliers equal or greater than 25,000 acres

For estimating new costs, it is assumed that all water suppliers equal to or greater than 25,000 acres irrigated land are measuring water deliveries and reporting water use information in AWMPs, in accordance to the CWC requirements. The total cost for implementation of the four methods to these water suppliers, for a total of 6 million acres irrigated lands, would be about $6 million to $30 million per year.

Costs to water suppliers greater than 10,000 and less than 25,000 acres

For estimating new costs, it is assumed that all water suppliers greater than 10,000 and less than 25,000 acres (1) are not measuring water deliveries, (2) and water use information is not collected (CWC requires this category of suppliers to measure and report if funding is available). Therefore, the measurement of deliveries and water use information would have new costs to these water suppliers. The total costs to these water suppliers, for a total of 757,000 acres of irrigated land, would be about $8.8 million per year and a one-time cost of $15 million for installing water measurement devices.

Costs to water suppliers with 25,000 acres or greater for implementing field scale methods

In the proposed methodology, field scale methods would be voluntary, and a water supplier would select a representative sample of participating fields for field scale implementation. The total cost to a water supplier with 25,000 acres or greater (300 fields) for computing methods 1, 2 and 3 for field scale (assuming it is applied to 75 sites) is about $12,500 to $31,000 per year. Water delivery measurement to fields is required by CWC; therefore, no water measurement cost is included. If all the 75 fields are supplied by private groundwater that is not measured or estimated, the cost of groundwater measurement would be about $150,000 ($24/site) plus $50,000 per year ($8/acre/year).

Table ES-2 Summary of proposed methods for quantifying the efficiency of agricultural water use organized by spatial scale [1]

<table>
<tr><th>Method for quantifying efficiency of agricultural water use[2]</th><th>Implementing entity</th><th>Implementation schedule</th><th>Data needed</th><th>Estimated costs</th><th>Data reports</th></tr>
<tr><td colspan="6">Basin scale [3]</td></tr>
<tr><td>Crop consumptive use fraction (CCUF)

Method evaluates the relationship between the consumptive use of a crop and the quantity of water applied.
CCUF = ETAW/(AWb)</td><td rowspan="4">Basin-Alliance</td><td rowspan="4">Phase 1: first AWMP cycle after legislative authority is established

Phase 2: second AWMP cycle after legislative authority is established

Phase 3: third AWMP cycle after legislative authority is established</td><td rowspan="4">Regional values of ET, AU (including leaching, climate control, and seed germination), EU, Kc, AW, Pe, WS, and RF</td><td rowspan="4">Not estimated*</td><td rowspan="4">Supplier scale values of ET, Pe, ETAW, Kc, AW, AU (including leaching, climate control, and seed germination), EU, RF, CCUF,AWUF, TWUF, WMF, mean and standard deviation of field scale CCUF, AWUF, TWUF to be reported in AWMPs</td></tr>
<tr><td>Agronomic water use fraction (AWUF)

Method evaluates the relationship between the consumptive use plus the agronomic use of a crop and the quantity of water applied.

AWUF = [ETAW+AU]/(AWb)</td></tr>
<tr><td>Total water use fraction (TWUF)

Method expands on the CCUF by including water for crop agronomic use and to meet environmental objectives.

TWUF = (ETAW+AU+EU)/AWb</td></tr>
<tr><td>Water management fraction (WMF)

Method estimates the recoverable water available for reuse at another place or time in the system.

WMF = (ETAW+ RF)/AWb</td></tr>
</table>

Footnotes: See bottom of final section of this table.

Acronyms: See also definitions in section 3 of this report. AU: agronomic use; AWb, AWs, AWf: Basin, supplier, and field scale applied water (AW consists of surface diversions and/or deliveries and groundwater delivered to a boundary excluding non-agricultural uses and storage); AWMP: Agricultural Water Management Plan; ET: evapotranspiration; EU: environmental use; ETAW: Evapotranspiration of Applied Water; Kc: crop coefficient; Pe: effective precipitation; RF: recoverable flow; WS: water supplies.

*Basin scale costs are not estimated because basin scale is an option and costs depend on the size and number of water suppliers forming a basin alliance.

Table ES-2 (cont'd.) Summary of proposed methods for quantifying the efficiency of agricultural water use organized by spatial scale[(1)]

Method for quantifying efficiency of agricultural water use[(2)]	Implementing entity	Implementation schedule	Data needed	Estimated costs	Data reports
Supplier Scale[(4)]					
Crop consumptive use fraction (CCUF) CCUF = ETAW/(AWs) **Agronomic water use fraction (AWUF)** AWUF = [ETAW+AU]/(AWs) **Total water use fraction (TWUF)** TWUF = (ETAW+AU+EU)/AWs **Water management fraction (WMF)** WMF = (ETAW+ RF)/AWs	Water Suppliers ≥25,000 acres	**Phase 1**: first AWMP cycle after legislative authority is established **Phase 2**: second AWMP cycle after legislative authority is established **Phase 3**: third AWMP cycle after legislative authority is established	Supplier scale values of ET, Pe, ETAW, Kc, AW, AU(including leaching, climate control and seed germination),EU, RF, WS, FGD (See section 4.2.1.1)	$1 to $5 per acre per year	Supplier scale values of ET, Pe, ETAW, Kc, AW, AU(including leaching, climate control, and seed germination), EU, RF, FGD, CCUF,AWUF, TWUF, WMF, mean and standard deviation of field scale CCUF, AWUF, TWUF to be reported in AWMPs
Crop consumptive use fraction (CCUF) CCUF = ETAW/(AWs) **Agronomic water use fraction (AWUF)** AWUF = [ETAW+AU]/(AWs) **Total water use fraction (TWUF)** TWUF = (ETAW+AU+EU)/AWs **Water management fraction (WMF)** WMF = (ETAW+ RF)/AWs	Water Suppliers <25,000 acres			Cost: $24 per acre initial costs for measuring applied water and $2 to $5 per acre per year O&M and data management, and $6 per acre plus $2 per acre per year for O&M for recoverable flows if applicable	

Footnotes: See bottom of final section of this table.

Acronyms: See also definitions in section 3 of this report. AU: agronomic use; AWb, AWs, AWf: Basin, supplier, and field scale applied water (AW consists of surface diversions and/or deliveries and groundwater delivered to a boundary excluding non-agricultural uses and storage); AWMP: Agricultural Water Management Plan; ET: evapotranspiration; EU: environmental use; ETAW: Evapotranspiration of Applied Water; Kc: crop coefficient; Pe: effective precipitation; RF: recoverable flow; WS: water supplies.

Table ES-2 (cont'd.) Summary of proposed methods for quantifying the efficiency of agricultural water use organized by spatial scale(1)

Method for quantifying efficiency of agricultural water use(2)	Implementing entity	Implementation schedule	Data needed	Estimated costs	Data reports
Field Scale(5)					
Crop consumptive use fraction (CCUF) CCUF = ETAW/(AWf) **Agronomic water use fraction (AWUF)** AWUF = [ETAW+AU]/(AWf) **Total water use fraction (TWUF)** TWUF = (ETAW+AU+EU)/AWf	Water Suppliers ≥25,000 acres	**Phase 1**: first AWMP cycle after legislative authority is established **Phase 2**: second AWMP cycle after legislative authority is established **Phase 3**: third AWMP cycle after legislative authority is established	Field scale values of ET, Pe, ETAW, Kc, AW, AU(including leaching, climate control, and seed germination), EU (See section 4.2.2.1)	\$2 to \$5 per acre per year	Mean and standard deviation of field scale CCUF, AWUF, TWUF to be reported in water supplier's AWMPs
Crop consumptive use fraction (CCUF) CCUF = ETAW/(AWf) **Agronomic water use fraction (AWUF)** AWUF = [ETAW+AU]/(AWf) **Total water use fraction (TWUF)** TWUF = (ETAW+AU+EU)/AWf	Water Suppliers <25,000 acres			\$24 per acre for measuring private groundwater measurement (if applicable) plus \$2 to \$5 per acre per year	

(1) Frequency of Calculations and Reporting: all basin, supplier, and field scale calculations should be done on annual time step and every five years reported in the AWMP.

(2) The WMF is computed using water supplier or basin estimates of ETAW, RF, and AW.

(3) A Basin-Alliance is a group of water suppliers who jointly implement the methodology. See sections 3 and 4 of this report.

(4) CCUF, AWUF, TWUF for supplier and field scales are based on measured/estimated values of ETWA, AW, EU, AU. CCUF, AWUF, and TWUF would also be statistically calculated over the entire supplier's service area based on the mean and standard deviation of available field scale calculated values, if supplier provides on-farm evaluation of irrigation systems.

(5) Field scale implementation would be accomplished by a State, federal, and supplier joint on-farm irrigation evaluation (such as done by mobile labs) program based on voluntary farmer participation. Consistent with the Water Code when locally cost-effective, program shall be sponsored by supplier if serving equal or more than 25,000 acres of irrigated land. For suppliers serving less than 25,000 acres of irrigated land, participation is recommended only when funding is made available.

Acronyms: See also definitions in section 3 of this report. AU: agronomic use; AWb, AWs, AWf: Basin, supplier, and field scale applied water (AW consists of surface diversions and/or deliveries and groundwater delivered to a boundary excluding non-agricultural uses and storage); AWMP: Agricultural Water Management Plan; ET: evapotranspiration; EU: environmental use; ETAW: Evapotranspiration of Applied Water; Kc: crop coefficient; Pe: effective precipitation; RF: recoverable flow; WS: water supplies.

Supplemental Indicators

In addition to the four methods for quantifying the efficiency of agricultural water use, DWR has included in this report four indicators that would provide supplemental information about irrigation and delivery system performance and crop productivity. These indicators do not quantify the efficiency of agricultural water use, but help estimate the limits of potential efficiency and productivity. Two of the indicators help describe the performance of the growers' irrigation system (how evenly water is applied and infiltrates into the soil) and the water supplier's delivery system (relationship of water diverted by the supplier to water delivered to its customers). The other two indicators help describe crop productivity (relationship of the volume of water applied to an area to the total crop yield and gross crop revenue). The purpose, application, and limitations of these four indicators are described in Section 5 and summarized in Table 5-1.

Four indicators are included to provide supplemental information about irrigation system performance and crop productivity. They do not quantify the efficiency of agricultural water use.

Indicators of Irrigation and Delivery System Performance

Two indicators provide supplemental information on the performance of irrigation systems—distribution uniformity (DU) and delivery fraction (DF).

- **Distribution Uniformity (DU).** This is a measure of irrigation system performance—how evenly water is applied and infiltrates into the soil across a field during an irrigation event. It is not a measure of how efficiently water is used on the field. A well designed irrigation system applies water to crops as uniformly as possible to optimize crop production. DU is applicable at the field scale. Under CWC §10608.48(c), many water suppliers may provide on-farm irrigation evaluation service, if locally cost effective, that include the determination of DU and other information of the irrigation system.

- **Delivery Fraction (DF).** This indicator evaluates the relationship (ratio) between the water delivered to water supplier customers and the agricultural water supplier's water supply. It is applicable at the water supplier scale, only. Under CWC §531.10 and CWC §10608.48, many water suppliers are required to determine and report aggregated farm-gate delivery and water supply—the components used to calculate delivery fraction.

Indicators of irrigation system performance:
- *DU – distribution uniformity*
- *DF – delivery fraction*

Indicators of Crop Productivity

During ASC and subcommittee meetings, two indicators relating crop productivity to applied water were identified and discussed. DWR has reported statewide trends for these indicators in the 2009 update of the California Water Plan. The two crop productivity indicators provide information about the relationship and trends of crop yield and/or monetary value to the volume of irrigation water applied during production. They can indicate long-term changes or trends in agricultural production and income relative to applied water at larger

Indicators of crop productivity:
- *PAW – Productivity of Applied Water Fraction*
- *VAW – Values of Applied Water Fraction*

spatial scales. However, these indicators do not quantify the efficiency of agricultural water use nor economic efficiency (see Section 5, Box 5-1 Economic Efficiency).[1]

Crop production depends on many factors other than the water to meet crop consumptive and non-consumptive needs, including water quality, climate, soil type, soil depth, crop parameters (variety), crop management (fertilizer and pest management, etc.) and water management (irrigation system, irrigation management, and water supply flexibility and reliability).

DWR cautions that the crop productivity indicators should not be used to draw conclusions about regional crop selection because many factors other than applied water affect crop selection, crop production, and crop value in any given year and location and with changing crop markets.

The crop productivity indicators should not be used to draw conclusions about regional crop selection.

Two indicators provide information on crop productivity: Productivity of Applied Water (PAW) and Value of Applied Water (VAW).

- **Productivity of Applied Water Fraction (PAW).** This indicator illustrates the relationship (ratio) between crop production in tonnage and the volume of applied water. It is most applicable at a statewide or county scale.

- **Value of Applied Water Fraction (VAW).** This indicator illustrates the relationship (ratio) between gross crop value in dollars and the volume of applied water. It is most applicable at the statewide and county scales.

DWR recommends reporting crop productivity and value of production for statewide and county scales. Application of the PAW and VAW at the field scale is difficult and limited by the lack of needed data; therefore, the field scale PAW and VAW indicators are included in the report for consistent use by growers and are considered voluntary for field scale application.

[1] The value of applied water indicator may substantially underestimate the final value of the commodity to the California economy. Example: alfalfa has a relatively low per acre farm-gate value compared to permanent crops and vegetables, but it is the nutritional foundation of the state's highest value commodity – milk.

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1 Introduction

The Water Conservation Act of 2009 (Senate Bill X7-7) directs the Department of Water Resources (DWR)—in consultation with the Agricultural Water Management Council, academic experts, and other stakeholders—to develop and report to the Legislature a proposed methodology for quantifying the efficiency of agricultural water use and a plan of implementation that includes estimated implementation costs and types of data that would be needed to support the methodology. The legislation does not authorize DWR to implement the methodology.

This report is intended to improve the understanding of agricultural water use and provides illustrative examples to demonstrate the complexity of quantifying the efficiency of agricultural water use.

1.1 Purpose and Use of the Methodology

The purpose of the methodology proposed in this report is to describe practical methods for quantifying the efficiency of agricultural water use by irrigated agriculture that can help evaluate current conditions and strategies for improving agricultural water management. The report is intended to improve the understanding of agricultural water use and provide illustrative examples to demonstrate the complexity of quantifying the efficiency of agricultural water use.

The anticipated users of these methods are farmers, water suppliers, and regional water management groups, as well as nongovernmental organizations and local, State, federal, and tribal planners. The methods are not intended for non-irrigated agriculture such as dairies production areas, on-farm processing, or other agricultural operations not directly related to irrigated lands.

The methods are not intended for non-irrigated agriculture such as dairies production areas, on-farm processing, or other agricultural operations not directly related to irrigated lands.

1.2 Legislative Direction and Declarations from Senate Bill X7-7 (Statutes of 2009)

Quantifying the efficiency of agricultural water use was directed by policy statements and other language in the 2009 legislation SB X7-7. Specifically, §10608.64 of the Act states:

> *§10608.64. The department, in consultation with the Agricultural Water Management Council, academic experts, and other stakeholders, shall develop a methodology for quantifying the efficiency of agricultural water use. Alternatives to be assessed shall include, but not be limited to, determination of efficiency levels based on crop type or irrigation system distribution uniformity. On or before December 31, 2011, the department shall report to the Legislature on a proposed methodology and a plan for implementation. The plan shall include the estimated implementation costs and the types of data needed to support the methodology. Nothing in this section authorizes the department to implement a methodology established pursuant to this section.*

DWR identified further legislative direction in Chapter 1, General Declarations and Policy of the 2009 legislation. This chapter provided guidance in the assessment of methodology and development of an implementation plan for quantifying efficiency of agricultural water use that included the following:

§10608. The Legislature finds and declares all of the following:

(a) Water is a public resource that the California Constitution protects against waste and unreasonable use.

(b) Growing population, climate change, and the need to protect and grow California's economy while protecting and restoring our fish and wildlife habitats make it essential that the state manage its water resources as efficiently as possible.

(c) Diverse regional water supply portfolios will increase water supply reliability and reduce dependence on the Delta.

(d) Reduced water use through conservation provides significant energy and environmental benefits, and can help protect water quality, improve streamflows, and reduce greenhouse gas emissions.

(e) The success of state and local water conservation programs to increase efficiency of water use is best determined on the basis of measurable outcomes related to water use or efficiency.

(f) Improvements in technology and management practices offer the potential for increasing water efficiency in California over time, providing an essential water management tool to meet the need for water for urban, agricultural, and environmental uses.

§10608.4. It is the intent of the Legislature, by the enactment of this part, to do all of the following:

(a) Require all water suppliers to increase the efficiency of use of this essential resource.

(e) Establish consistent water use efficiency planning and implementation standards for urban water suppliers and agricultural water suppliers.

(i) Require implementation of specified efficient water management practices for agricultural water suppliers.

(j) Support the economic productivity of California's agricultural, commercial, and industrial sectors.

(k) Advance regional water resources management.

§10608.8

(c) This part does not require a reduction in the total water used in the agricultural or urban sectors, because other factors, including, but not limited to, changes in agricultural economics or population growth may have greater effects on water use. This part does not limit the economic productivity of California's agricultural, commercial, or industrial sectors.

§10800

(e) There is a great amount of reuse of delivered water, both inside and outside the water service areas.

(f) Significant noncrop beneficial uses are associated with agricultural water use, including streamflows and wildlife habitat.

(h) Changes in water management practices should be carefully planned and implemented to minimize adverse effects on other beneficial uses currently being served.

The complete list of related CWC sections can be found in Appendix A.

1.3 Process

The process for developing this proposal was time consuming because of the complexity of the technical subject matter and the variability of agricultural water management and operations throughout California.

DWR began the process of developing a methodology for quantifying the efficiency of agricultural water use by forming a subcommittee (known as A1). The A1 subcommittee is a subgroup of the larger Agricultural Stakeholder Committee (ASC) that was formed to advise the DWR on implementation of the agricultural water conservation and planning provisions of Senate Bill X7-7, the statutes of 2009. In advance of convening stakeholder work on the A1 topic, DWR contacted the ASC by email on July 14, 2011, and solicited member feedback about "*any initial suggestions or developed proposals on methodologies for quantifying the efficiency of agricultural water use (and related materials)… to be reviewed by the ASC and considered by DWR*." In its email, DWR also requested that ASC members volunteer to serve on the A1 subcommittee and/or recommend other participants. The A1 group was subsequently formed, composed of Agricultural Water Management Council members, academic experts, agricultural water suppliers, and environmental stakeholders. Participants were not required to be members of the ASC or be affiliated with an ASC member.

A subgroup of the Agricultural Stakeholder Committee (ASC), the A1 subcommittee is composed of Agricultural Water Management Council members, academic experts, agricultural water suppliers, and environmental stakeholders. A1 members need not be members of the ASC nor affiliated with an ASC member.

Preliminary discussion about quantifying the efficiency of agricultural water use started during the ASC meeting on August 3, 2011, during which DWR presented a document titled "Discussion Paper 1 - Initial Draft Methodology for Quantifying the Efficiency of Agricultural Water Use (Project A1)". This paper was discussed by the ASC as were the various proposals sent in response to the July 14 email. These discussions led to convening the first A1 subcommittee meeting on August 10, 2011. Consistent with the SBx7-7 program wherein various subcommittees have been formed to support the ASC (and its urban counterpart the Urban Stakeholder Committee), the A1 subcommittee was provided a "Charge" by DWR and the ASC, describing the subcommittee's role, responsibility, and expectations. The subcommittee was also instructed by DWR and the ASC that all decision-making and communication protocols would be conducted as per the existing ASC Charter. The subcommittee met five times between August 10, 2011, and November 2, 2011. During this time, the ASC was convened once on September 16, 2011, to receive an update from the A1 subcommittee and DWR. This update was in the form of discussion about a draft table presenting various methods for quantifying agricultural water use efficiency. This meeting also included several presentations and associated discussions about economic factors associated with quantifying water use efficiency.

The A1 subcommittee was also instructed by DWR and the ASC that all decision-making and communication protocols would be conducted as per the existing ASC Charter.

After numerous revisions of the discussion paper, methods table, and associated background materials and extensive input from the A1 subcommittee participants, A1 subcommittee work was deemed completed and a draft version of the document titled "Quantifying the Efficiency of Agricultural Water Use" was released for ASC review on November 15, 2011. Public comments were considered by DWR in preparing this report. During the process, numerous approaches and metrics were considered; and those that were not included in the proposed methodology are listed in Appendix E.

The ASC was again convened on November 16, 2011, to walk through the draft report. Feedback at this meeting reflected a general dissatisfaction of ASC members that there was not sufficient time for them to review and comment on the document (this sentiment was expressed by members several times throughout the entire process as DWR was oftentimes challenged to provide materials to the ASC with sufficient review time in advance of their meeting). Therefore, a follow-up webinar was held on November 30, 2011 to allow ASC members and other interested parties an opportunity to discuss the document after a reasonable time for review.

In advance of the webinar, DWR conducted two public workshops about the A1 process on November 21 and 22, 2011, in Willows and Fresno, California, respectively. The purpose of these meetings was to describe the draft document and to solicit input from directly affected agricultural water users and suppliers. Prior to these workshops, several ASC members had expressed concern that although the A1 and ASC discussions reflected the sentiments of water districts, suppliers, academicians, consultants, and agricultural and environmental advocates, these discussions did not reflect input from "on-the-ground" water users that were likely to be impacted by some proposed quantification methods. Despite this intended outcome of the public workshops, they were minimally attended. A total of 26 general public participants attended the Willows workshop, and 10 attended the Fresno workshop.

The ASC was convened again on December 21 which was followed by two more full ASC meetings on February 7 and April 24, 2012. The purpose for these latter three ASC meeting was to continue iterative improvements and revisions to the draft report and to identify all opportunities for mutually acceptable quantification methods among the diverse ASC members. Between the February and April meetings, DWR also met individually and with small groups of ASC members to discuss and attempt to resolve outstanding issues of dispute, most notably the applicability, relevance, and presentation of the crop productivity indicators. These meetings also included several discussions with representatives from the California Department of Food and Agriculture (CDFA), which is not a member of the ASC but was engaged throughout the process as an affected State agency and advocate for agricultural interests.

Although not a member of the ASC, representatives from the California Department of Food and Agriculture were engaged throughout the process as an affected State agency and advocate for agricultural interests.

The stakeholder process culminated at the April 26, 2012 meeting wherein 16 ASC members reviewed the proposed final draft document section by section. The members identified (using the decision process in their charter) their various levels of support for each section using a "straw poll" preliminary voting method. Although not all the ASC members attended the April meeting, the participants (including members of the public) reflected the perspectives of most of the members that had consistently attended most A1-related ASC meetings. Generally, all interests were represented (agricultural and environmental advocacy, water suppliers and districts, academia and extension services, the CDFA and U.S. Bureau of Reclamation). Through this discussion, it was determined that almost all sections of the document could be accepted by all members except for the following:

Method 4, Water Management Fraction – One ASC member proposed deletion of Method 4. Two members opposed the deletion of Method 4. The rationale to remove the Method 4 was that it would create an undue amount of work for DWR and water suppliers. However, the members who proposed that Method 4 be deleted later contacted DWR staff and withdrew their proposal to delete Method 4 from the report.

Section 5, Supplemental Indicators – Various approaches were considered about where the information in Section 5 should reside in the report. This discussion reflected the principal unresolved item for the entire process and, in particular, the discussions that took place in ASC and sidebar meetings in 2012. The outcome of the April 24 discussion reflected no resolution of the issue by the

ASC members. When presented three options, the ASC provided the following straw votes:

- Keep the Supplemental Indicators in Section 5 - 10 members (agricultural and environmental interests) were opposed.

- Move the entire Supplemental Indicators section into an appendix - 2 environmental advocacy members were opposed.

- Move the Supplemental Indicators information from Section 5 into Section 3 with the methods for quantifying the efficiency of agricultural water use. – 15 members (principally agricultural interests) were opposed.

DWR kept the Supplemental Indicators in Section 5.

Throughout the process, the members of the ASC and A1 subcommittee provided extensive personal commitment and travel time to attend meetings and review multiple iterations of materials that were created to address this exceptionally complex topic. It is difficult to calculate the total effort expended to create, discuss, revise, and finalize this document, but it is accurate to conclude that thousands of hours were volunteered collectively by the affected and interested parties. This document would not have been prepared to its current level of quality and insight without that support.

1.4 Report Organization

This report is organized with the following sections:

Legislative Direction, Purpose, and Process. The context, purpose, and process for developing a methodology [Section 1].

Water Use and Water Use Efficiency in Agriculture. Water balances at different spatial scales are presented to show how water is used for irrigated agriculture and opportunities for water use efficiency [Section 2].

Methodology for Quantifying the Efficiency of Agricultural Water Use. A discussion of four methods to quantify the efficiency of agricultural water use [Section 3].

Plan of Implementation. Roles and responsibilities, implementing entities, data needs and sources, reporting, schedule/phasing, data management, and cost estimates that would be needed to implement the methodology [Section 4].

Supplemental Indicators. A discussion of indicators that provide supplemental information about irrigation system performance and crop productivity [Section 5].

Appendixes A through F. (A) Selected sections of the California Water Code, (B) maps, (C) calculation examples for methods and indicators, (D) parameter descriptions and calculations, (E) other metrics considered but not included in the methodology; and (F) glossary of terms.

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2 Water Use and Water Use Efficiency in Agriculture

2.1 Water Use in Agriculture

Surface water and groundwater used for irrigation of crops are commonly referred to as applied water.

Agriculture is important to California's economy, and water is essential for irrigated agriculture (see Box 2-1 Farming, Water, and California's Economy). Agricultural water uses are met from precipitation, surface water diversions, groundwater pumping, and shallow groundwater. Surface water and groundwater used for irrigating crops are commonly referred to as *applied water*. The purpose of irrigation is to maintain soil moisture for crop use and soil salinity at levels that do not restrict crop growth.

Various irrigation methods are used to apply water to irrigated lands in California, including traditional furrow, improved furrow, border/flood irrigation, micro (drip and other low application emitters), and sprinkler irrigation[2]. Over the past 25 years, there has been a significant shift from gravity and sprinkler irrigation systems to drip and micro and subsurface systems.

Most irrigation water is supplied by agricultural water suppliers (irrigation districts, water districts, canal companies, etc.). Water suppliers deliver water to their customers' fields by using water storage and conveyance facilities. They may operate these water deliveries through open channels or pipes and flow control structures and water measurement devices. Some water suppliers use their entire water supply and recycle and reuse their tailwater (spills from the conveyance systems) within their service area boundary.

Some water suppliers may be in a basin, and the tailwater from some suppliers may flow to other suppliers, to streams and rivers, or to salt sinks. In some cases, agricultural water suppliers have/are forming basin alliances to improve water and water quality management on a basin scale.

[2] The results of DWR's 2010 irrigation system survey are posted at http://www.water.ca.gov/landwateruse/surveys.cfm

Box 2-1 Farming, Water, and California's Economy

Farming is an important part of California’s economy and the daily lives of many Californians. As one of only five Mediterranean growing regions in the world, California is one of the most productive agricultural regions in the world. California agriculture produces more than 400 crops—fruits and vegetables, nuts, grains, meat, dairy, cotton, and more—on more than 81,700 farms and ranches, employing about 800,000 people. California farmers and ranchers serve diverse customer needs, from small farmers producing for local markets to extensive international trade.

California agriculture is a $37.5 billion annual industry, generating 12 percent of total U.S. agricultural revenue and $100 billion in related economic activity. In addition, California exports 23 percent of the products grown and harvested in the state. California provides more than half the nation’s fruits, nuts, and vegetables alone. The top 10 crops for export are almonds, rice, wine, pistachios, walnuts, dairy, table grapes, processing tomatoes, oranges, lettuce.

Water is an essential part of irrigated agriculture. In water year 2,000, California irrigated an estimated 9.6 million acres of cropland (includes multi-cropping) using roughly 34 million acre-feet of applied water. California farmers and water suppliers are constantly innovating, adopting new technologies, improving water and operational efficiencies, and reducing costs of production. DWR estimates that over the past 40 years, the rising real value of agricultural products, coupled with a reduction in applied water use, has nearly doubled the gross revenue generated per acre-foot of applied water (see California Water Plan Update 2009, Volume 4, Comparing Changes in Applied Water and Real Gross Value of Output for California Agriculture).

2.2 Understanding Water Use Efficiency

Water conservation is defined by the CWC §10817 as *the efficient management of water resources for beneficial uses, preventing waste, or accomplishing additional benefits with the same amount of water*. Implementing water use efficiency measures are means for reducing water diverted or delivered to meet crop water requirements or other beneficial uses. Water conservation and water use efficiency may result in water savings and/or co-benefits including improved water quality, energy savings, and reduced greenhouse gas emissions. Water saved can be used to meet agricultural, urban, and environmental water demands. Applied irrigation water that becomes surface tailwater or deep percolation that is recoverable may be used by other farmers, cities, or the environment. However, being more efficient in some circumstances may mean more costs and more energy use. As a result, third party impacts should be fully considered before mandating any significant water conservation or efficiency measures.

Agricultural water use can be categorized as consumptive (irrecoverable) or non-consumptive (recoverable). Consumptive use refers to water that is unavailable for reuse, e.g., evaporation, plant evapotranspiration, incorporation into plant biomass, seepage to a saline sink, or unavailability due to contamination. Non-consumptive use such as leaching or tailwater, on the other hand, refers to water that is available for reuse (e.g., through return flows or groundwater recharge).

Agricultural water use can be categorized as consumptive (irrecoverable) or non-consumptive (recoverable).

While applying water for crop production, including crop transpiration and leaching salts from the root zone, other incidental uses may occur. Those uses that do not contribute to crop production may include water transpiration from weeds and riparian vegetation and evaporation from reservoirs, canals, sprinklers, soil, and plant surfaces. Water uses for crop production (consumptive and agronomic use), environmental use, and other incidental uses can be either consumptive or non-consumptive. Table 2-1 presents examples of consumptive and non-consumptive uses that are developed in part based on the description provided by Heermann and Solomon (2007). In general, water uses that are incidental to crop production and environmental use may be reduced to increase the efficiency of agricultural water use, in particular irrecoverable flows.

Table 2-1 Examples of consumptive (irrecoverable) and non-consumptive (recoverable) uses of water

	Consumptive use (irrecoverable)	**Non-consumptive use (recoverable)**
Water uses for crop (consumptive and agronomic) and environmental use	Crop or vegetative evapotranspiration	Leaching
	Evaporation for cooling or from soil during seed germination	River/stream flows
	Plant evapotranspiration for frost control	
Water uses incidental to crop and environmental use	Deep percolation/flow to salt sink	Operational spills
	Phreatophyte evapotranspiration	Tailwater
	Weed evapotranspiration	Deep percolation
	Reservoir and canal evaporation	

This report recognizes the ecosystem services and benefits that irrigated agriculture and agricultural crops provide, from wildlife habitat to carbon sequestration. Although all co-benefits are not quantifiable, water dedicated for environmental purposes is included in quantifying the efficiency of water use. Thinking about water in a systems approach recognizes that simply reducing applied agricultural water may not necessarily result in a net benefit at farm, basin, or watershed levels and that effective agricultural water stewardship may provide multiple ecosystem services (see Box 2-2 California Agricultural Stewardship - A Systems Approach).

Agricultural water stewardship is "the responsible use and management of water that optimizes agricultural water use while addressing the co-benefits of water or food production, the environment, and human health."

from: California Roundtable for Food and Water Supply http://agwaterstewards.org/

To develop a methodology to quantify the efficiency of agricultural water use, a water balance approach was considered to look into the various components of water use in agriculture including water used for environmental use associated with irrigated lands (see Section 3). Other uses of water in agriculture—dairy production areas, washing products, etc.—are not included in the water balance because they represent small fractions of the total water use in most cases and are difficult to quantify.

A water balance is a representation of all sources and dispositions of water into and out of a defined three-dimensional boundary (such as a water supplier including its surface area and subsurface volume) over a defined period of time. From these water flow elements, various relationships can be evaluated to describe the current water management conditions and assess opportunities for change. Understanding components of a water balance and their relationships within a defined boundary is fundamental to understanding how efficiently the water is used.

A water balance is a representation of all sources and dispositions of water into and out of a defined boundary over a defined period of time

Because hydrologic, regulatory, distribution, and other features of a water balance are unique to a specific boundary, water balances can look different, reflecting the unique circumstances of different boundaries.

Box 2-2 California Agricultural Water Stewardship - A Systems Approach

California is facing significant challenges around the management of water for all users. For agricultural water use, understanding water systems means thinking about the use of water both at the farm level and in the context of the larger watershed. Taking a more expanded view of agricultural water use efficiency, agricultural water stewardship can be thought of as:

> *The responsible use and management of water that optimizes agricultural water use while addressing the co-benefits of water for food production, the environment, and human health.*

This definition has been developed by a diverse group of California stakeholders, including policy, environmental and agricultural leaders affiliated with the California Roundtable for Water and Food Supply who understand that agricultural water management decisions need to consider the broader ecological, social, and economic context.

A systems approach to water management recognizes that effective stewardship may provide multiple ecosystem services. In addition, simply reducing applied agricultural water on an individual farm may not necessarily result in improved availability for other users in the watershed. Furthermore, while growers are continually making improvements in their operations to ensure profitability and the quality of the resource base, they are doing so within a system: gains in overall sustainability may mean the increased use of applied water or other individual inputs.

As an example, many growers in California use cover crops to provide nitrogen and improve soil quality. Cover crops may in fact require additional applied water, depending on the crop, rainfall, planting date and other factors. However, the overall resource base may be improved, by reducing applied synthetic nitrogen, improving soil quality, and protecting groundwater. Making smart water use decisions while minimizing environmental impacts and balancing all the trade-offs will help ensure the long-term viability of agricultural production for California.

For more information and case studies, see http://agwaterstewards.org/

In this report, water use efficiency fractions that are a ratio of outputs from an agricultural system to an input to the agricultural system in volumes and/or depths of water were considered for quantifying the efficiency of agricultural water use – and they are referred to as methods. Input to an agricultural system is the volume of applied water. Outputs from agricultural systems include evapotranspiration from crops (ET), agronomic use such as leaching salts, evaporation during seed germination, climate control (frost protection and cooling), environmental water use, tailwater, deep percolation, evaporation from open water surfaces, and evapotranspiration by non-crops (weeds, for example). The ratio of selected outputs (crop evapotranspiration, crop agronomic use, and environmental water use) to inputs (applied water) is used to quantify the efficiency of water use. Other outputs (evaporation from soil or water surfaces in excess of ET, evapotranspiration by non-crop vegetation, and flow to salt sinks, etc.) are not quantified and may be estimated in total as residual in the water balance. Crop evapotranspiration, crop agronomic uses (leaching, evaporation during seed germination, evaporation for cooling or application for frost control) and evaporation and evapotranspiration for environmental purposes are intended uses (outputs).

In this report, all water use efficiency fractions that are a ratio of outputs from an agricultural system to an input to the agricultural system in volumes and/or depths of water were considered for quantifying the efficiency of agricultural water use – and they are referred to as methods.

In order to quantify the inputs and outputs of an agricultural system, it is necessary to establish physical as well as time boundaries. These boundaries are referred to as spatial and temporal scales in this report. Selected components of the water balances are used to quantify the ratio of outputs to inputs for quantifying the efficiency of agricultural water use at each spatial scale for a given time scale.

There is no single equation to represent the efficiency of agricultural water use at all scales. As the area within a boundary (scale) increases, the complexity and amount of data needed to calculate the water balance or water use efficiency generally increase. The water use efficiency at a smaller scale cannot be aggregated to arrive at water use efficiency at a larger scale. For example, although a weighted average (by acreage) of the water use efficiencies from fields within a water supplier boundary indicates the average field conditions in the supplier’s service area, it should not be used to derive water use efficiency of the water supplier. Rather, the supplier’s scale would take into account the flow of water to, from, and between fields (i.e., return flow, reuse, and seepage and spill flows) and water to and from groundwater storage, meeting environmental objectives, or other non-traditional uses that affect the operation and management of agricultural water. Therefore, understanding water use efficiency may require implementation of all the methods proposed in this report.

There is no single equation to represent the efficiency of agricultural water use at all scales.

3 Methodology for Quantifying the Efficiency of Agricultural Water Use

The quantification of water use efficiency needs to recognize and consider the fate of water at different spatial levels. The water balance discussed here provides a useful framework for understanding and quantifying agricultural water use efficiency. Measurement and quantification of all the water balance components, such as parsing evaporation and transpiration into its parts, is a technical challenge; therefore, the components of the water balance used in this report to quantify the efficiency of agricultural water use are the components of the water balance that can be measured or quantified using models.

3.1 Spatial Scales Considered

For purposes of developing a methodology, DWR considered the following spatial scales that closely align with fields, delivery systems, and basin water management (Figure 3-1).

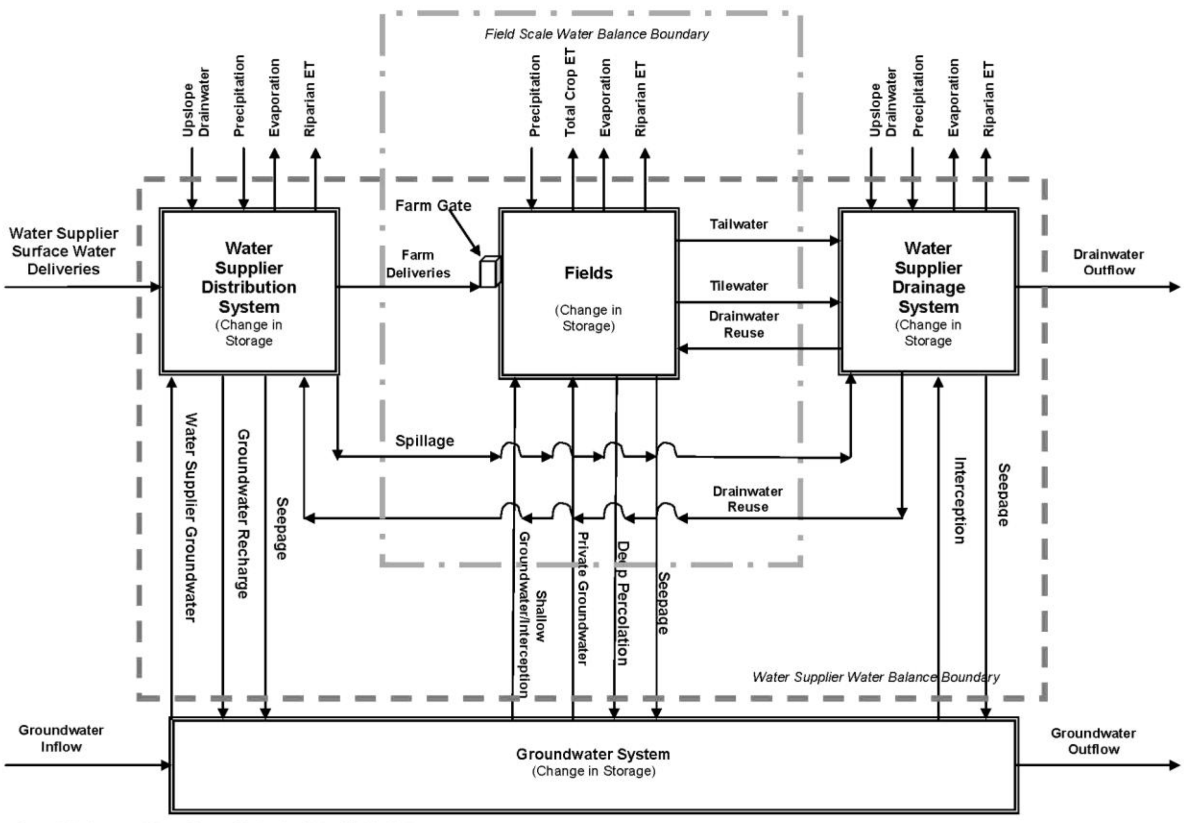

Figure note: Crop ET is crop evapotranspiration; riparian ET is evapotranspiration by vegetation, weeds, and phreatophytes. Evaporation is loss of water from surface of water or soils. Tailwater is the water flowing out from fields; tilewater is the drainage flow captured by drains. Seepage is outflow of water from canals or reservoirs; deep percolation is downward flow of water into groundwater.

Figure 3-1 Schematic diagram of water supplier and field scale water balance

3.1.1 Water Supplier Scale or Basin Alliance Scale

The water supplier scale is a term used to define a boundary of agricultural irrigated land served by the water supplier. The water supplier is an entity, either publicly or privately owned, that distributes or sells water for ultimate resale to customers. The water supplier scale allows an assessment of attributes associated with the operation and management of a water delivery and drainage system within the defined service area of a water supplier. The goal of an agricultural water supplier is to use infrastructure and management to deliver water supplies to the customers' fields. Information regarding water flows at this scale allows for evaluation of the relation between water brought into the boundaries of water supplier and the effectiveness of meeting the primary goal of delivering water to the fields for meeting crop water needs and additionally providing for efficient delivery of the water suppliers system to improve water use efficiency[3].

The water supplier scale allows an assessment of attributes associated with the operation and management of a water delivery and drainage system within the defined service area of a water supplier.

According to CWP, California has about 9 million acres of irrigated land (DWR 2009). DWR has identified 270 water suppliers in the state covering over 7.0 million acres of irrigated land. Table 3-1 presents the number of water suppliers and irrigated acres, known to DWR, in four size categories.

Water suppliers are defined in sections 10608.12(a) and 531.1(b) of the California Water Code.

Table 3-1 Agricultural water suppliers known to DWR (2011)

Acreage (A) categories	Number of suppliers	Irrigated lands, acres	Federal suppliers*	
			Number of suppliers	Acres
A < 2,000	48	45,369	1	1,334
2,000 ≤ A < 10,000	95	453,894	28	152,527
10,000 ≤ A < 25,000	50	757,640	20	315,749
A ≥ 25,000	77	5,862,081	29	2,267,486
Total	270	7,158,894	78	2,737,486

- Federal water suppliers – part of total number of water suppliers

Basin scale allows an assessment of a variety of attributes associated with basin water use and management within the basin boundary by two or more water suppliers. Because recoverable flows from one supplier may be used in another supplier's service area, the basin alliance scale is proposed as an option. Water balance components at a basin are similar to those of water supplier. Details of the basin alliance are described in Section 4.

Basin scale allows an assessment of a variety of attributes associated with basin water use and management within the basin boundary by two or more water suppliers.

At a basin scale, water is used on two or more water supplier areas. Each supplier may have its own independent water supplies. But the recoverable flows from one supplier may be used as a source of water supply for another supplier in the

[3] Water supplier is defined by Section 10608.12 (a) of CWC as "Agricultural water supplier" means a water supplier, either publicly or privately owned, providing water to 10,000 or more irrigated acres, excluding recycled water. "Agricultural water supplier" includes a supplier or contractor for water, regardless of the basis of right, that distributes or sells water for ultimate resale to customers. "Agricultural water supplier" does not include DWR. For purposes of Section 531.1 (b) of the CWC "Agricultural water supplier" means a supplier either publicly or privately owned, supplying 2,000 acre-feet or more of surface water annually for agricultural purposes or serving 2,000 or more acres of agricultural land. An agricultural water supplier includes a supplier or contractor for water, regardless of the basis of right, which distributes or sells water for ultimate resale to customers.

basin. Water balance inputs into the basin are surface water and groundwater flows and precipitation; outputs are evaporation, crop evapotranspiration, non-crop evapotranspiration (such as environmental uses), non-agricultural uses, and surface and subsurface outflows. The time scale for a water balance calculation is generally over a period of a year.

Water Supplier Scale Water Balance

Inputs and outputs of the water balance at a water supplier scale are conceptually similar to those listed above for a basin. The components of the water balance at a supplier scale are shown in Figure 3-1. Water diverted into a supplier's service area distribution system may be stored in short-term regulating storage from which water may be depleted by evaporation or infiltration into an aquifer as deep percolation. Water supplies from storage or directly from a source, whether surface water or groundwater, are conveyed to suppliers' customers by supplier and farm-level conveyance systems. Water also leaves the conveyance system as evaporation and seepage or evapotranspiration. Conveyance systems may also have spills during operation that may be captured and recycled or may flow into streams or infiltrate into groundwater aquifers.

Specific water uses include crop consumptive use, agronomic uses such as water application prior to seeding, and flooding fields to hasten the decomposition of straw, which has a dual environmental purpose of providing habitat for migrating fowl. Other environmental uses may include sustaining riparian habitat and supporting endangered species.

In Figure 3-1 (see also Table 2-1) consumptive uses (irrecoverable) for crop and environmental objectives are crop evapotranspiration (ET), Riparian ET, or evaporation for cooling. Consumptive uses that are incidental to crop and environmental uses are deep percolation to salt sinks, Riparian ET if by weeds or phreatophytes, and canal evaporation. Non-consumptive uses (recoverable) are leaching/seepage/deep percolation and drainage outflow to streams or rivers. Non-consumptive uses that are incidental to crop and environmental uses are spills, tailwater, and deep percolation.

Some of the deep percolation and tailwater may recharge groundwater aquifers or flow into streams and rivers, creating a source of supply for other water users. Water suppliers use the recoverable flow in a reuse system, or it flows to downstream suppliers. Although some surface and subsurface flows are recoverable, the reduction of recoverable flows may be desirable if it is necessary to improve water quality and reduce energy use and greenhouse gas emissions. After running off the field, recoverable flows are generally higher in nutrients; and energy may be needed to reuse water. Prevention or reduction of irrecoverable flows creates water savings that may be used for other beneficial uses.

3.1.2 Field Scale

The water delivered to farms is used for irrigation of crops to meet the crop consumptive use and agronomic use (further discussed in this section). Some water may also be used at the farm level for environmental purposes. Environmental water either evaporates or flows into streams or infiltrates into groundwater aquifers.

Field scale assessments allow an operator to evaluate the performance of an irrigation system for a particular crop at a particular point in time or across a defined time period, such as a growing season.

The field scale, a term used to define the boundary of a parcel(s) of land served by an irrigation method or system, allows an assessment of a variety of attributes associated with irrigation system(s) and management within a field. Field scale assessments allow an operator to evaluate the performance of an irrigation system for a particular crop at a particular point in time (such as an irrigation event) or across a defined time period, such as a growing season. This assessment will allow an operator to assess the effectiveness of the existing irrigation system and its management to meet the water needs of the crop and minimize deep percolation, non-crop evaporation, and surface outflows.

In some cases, more than one field is irrigated from the same supplier turnout. If all fields are using the same kind of irrigation system to irrigate the same crop, the group of fields can be assessed as one field. If the individual fields are growing different crops or using different kinds of irrigation systems, they should not be grouped into a single measurement/evaluation; and all individual crops/irrigation systems should be treated separately for quantifying the efficiency of water use. If the field scale efficiency is to be quantified for one or more such fields, additional effort is required to measure or estimate the water delivered to each of the fields.

If the individual fields are growing different crops or using different kinds of irrigation systems, they should not be grouped into a single measurement / evaluation; and all individual crops/irrigation systems should be treated separately for quantifying the efficiency of water use.

Field Scale Water Balance

A water balance schematic at the field scale is shown in Figure 3-1. Irrigation water applied (applied water) to the field is used to meet the various types of crop requirements including crop evapotranspiration (transpiration from crops and evaporation from soil surface), soil salinity leaching requirement, and other agronomic requirements. Some of the applied water may percolate beyond the root zone and may not be available for crop uptake within the field but may become available for use beyond the field scale or flow into salt sinks. Conversely, shallow groundwater may move into the root zone by capillary rise for crop uptake, or groundwater may be used at the field scale. Tailwater or tile water may be captured and reused on the same field, may flow out of the field and be reused on other fields, may support environmental water use in and along the drains, or may be lost to non-crop evapotranspiration or salt sinks. Some of the crop water requirements may be met through rainfall. Depending on the slope, soil type, timing, frequency, and intensity of precipitation, only a fraction of the total rainfall may be used by crops.

Agricultural water use that benefits crop production includes crop evapotranspiration, leaching, evaporation from soil during seed germination climate control (cooling and frost protection), soil preparation, and evapotranspiration by non-crops that are used as wind breaks.

Some amount of the applied water is used to leach excess amounts of salt that is present in the soil below the root zone to make an optimum condition for crop production. Different crop types and different varieties of the same crop can have different tolerances to salinity. This leaching requirement is the amount of water required to maintain soil salinity at an acceptable level and is estimated using the ratio of the electrical conductivities of irrigation water and drainage water. Water applied in excess of the leaching requirement that goes to deep percolation reduces field scale water use efficiency, but may be recovered later or elsewhere at the supplier or basin scale. However, achieving water use efficiency at the field scale saves water at the field and helps improve water quality, reduce energy use, and reduce non-crop evapotranspiration and irrecoverable flows.

Some amount of the applied water is used to leach excess amounts of salt that is present in the soil below the root zone to make an optimum condition for crop production.

Water may also be applied for cooling of crops and frost protection. The amount of water used for cooling and frost protection depends on crop type and weather parameters such as humidity and temperature and on the characteristics of the irrigation system and its management. Although some amount of water used for climate control may evaporate, the rest infiltrates into the soil or runs off. Some infiltrated water may become available for crops to consume or result in deep percolation that reduces field scale water use efficiency.

3.2 Water Use Efficiency Quantification Methods

The methodology proposed by DWR in this report consists of four methods and associated procedures to quantify the efficiency of agricultural water use at different spatial scales, hereafter referred to as Water Use Efficiency Quantification Methods (Methods). A methodology consists of a collection of the methods that are available for quantification of different attributes of efficiency of agricultural water use at different scales. These methods are not intended for non-irrigated agriculture such as dairies production areas, on-farm processing, or other agricultural operations not directly related to irrigated land. But irrigated acres in a dairy production are considered irrigated lands.

The methodology proposed by DWR in this report consists of four methods and associated procedures to quantify the efficiency of agricultural water use at different spatial scales, hereafter referred to as Water Use Efficiency Quantification Methods (Methods).

The primary approach for quantifying the efficiency of agricultural water use is by evaluating the relationships among particular components of a water balance. Simply stated, for the purposes of quantifying the efficiency of agricultural water use, the outputs of Crop ET and Riparian ET (for environmental purposes) and any water used for agronomic practices (whether in the form of ET or deep percolation) are compared to the applied water (input into the boundary).

These relationships may include volume of water use attributed to evapotranspiration, agronomic practices as well as environmental uses compared to the volume of applied water within the boundary under consideration. The water use efficiency quantification methods evaluate the efficiency of water applied intended for irrigating agriculture and meeting environmental objectives. Each of the four methods is described below in detail.

The water use efficiency quantification methods reported at various spatial scales provide valuable information to growers and their associated agricultural water suppliers or basin alliances. And to the extent the methods are reported beyond the field or supplier scale, they can also provide insight and understanding to regional, State, and federal policy-makers and planners. Example calculations for each method are presented in Appendix C.

Appendix C includes example calculations for each of the four methods at relevant spatial scales.

Results of these methods cannot be viewed independently. Each method provides a unique understanding of the efficiency of agricultural water use in an area. In fact, using these methods in tandem allows not only for quantifying each water use fraction separately, but for comparing the proportions of water used for different purposes (e.g., crop consumptive use, agronomic use, environmental use). The following four methods when taken together characterize existing water uses, and can inform water management decisions about alternative efficient water management practices (EWMPs).

Method 1: Crop Consumptive Use Fraction (CCUF). *Purpose:* It quantifies the efficiency of water use for the purpose of crop evapotranspiration. It evaluates the relationship between the consumptive use of a crop and the quantity of water applied within the boundary. Method 1 is recommended for field, water supplier, and basin scales.

Method 1 quantifies water use efficiency for the purpose of crop evapotranspiration.

Equation 1

$$CCUF = [ETAW]/[AW]$$

where ETAW and AW are in units of inches per year or acre-feet per year

- CCUF is calculated where **Evapotranspiration of Applied Water (ETAW)** is crop evapotranspiration minus the amount of precipitation evapotransipred by the crop,

Equation 1-A

$$ETAW = ET - Pe$$

where ET and Pe are in inches per year or acre-feet per year

  - **Crop evapotranspiration (ET)** is transfer of water to the atmosphere by the combined processes of evaporation from crop and soil surfaces and transpiration from crops. It is the amount of water that the crop needs for optimal growth and to produce yield. In quantifying the efficiency of agricultural water use at all spatial scales, the implementing entity can either measure ET or estimate it using theoretical and/or empirical equations. Measurement methods

CCUF = [ETAW]/[AW]
AW - applied water
CCUF- crop consumptive use fraction
ETAW - evapotranspiration of applied water
ET - crop evapotranspiration
ETo - reference evapotranspiration
EWMP - efficient water management practice
Kc - crop coefficients
Pe – effective precipitation

use complex equipment such as Eddy Covariance, Bowen Ratio, and lysimeters, which are very complex and therefore costly. The most commonly used approach for estimating ET is to use reference evapotranspiration (ETo) and crop coefficients (Kc), as described by DWR California Irrigation Management Information System (CIMIS) (http://wwwcimis.water.ca.gov/cimis/welcome.jsp). Selection of proper Kc values for the crops should be done by professionals using published data (such as the University of California Cooperative Extension). Recent studies (Sanden et al., 2012) indicate that Kc values were different from previously published values. Other equivalent methods are also used including energy balance (Allen et al., 2007a, 2007b; ASCE, 2005; Bastiaanssen, 1998, 2000).

Example Application of method 1:
An environmental coalition wants to demonstrate the improvements in efficiency that would result from projects. The coalition will document the existing CCUF of four different fields served by four unique stream diversions. An estimated reduction in applied water from modified irrigation management will be shown to reduce one of the factors, applied water, and show an improvement in CCUF.

Equation 1-B

$$ET = Kc * ETo$$

- **Effective precipitation (Pe)** is the fraction of precipitation water that is available for crops to use. Because a part of the precipitation becomes tailwater, deep percolation, and evaporation, only a fraction of the total precipitation is available to satisfy crop water needs. Pe depends on many factors including the slope of the land, soil type, soil moisture content, rainfall characteristics, weather conditions, and plant type. It is highly recommended that the method used has proven accuracy for estimating Pe for the area of interest. A soil moisture balance might be needed to determine with less uncertainty how much precipitation is available for crop uptake. This is especially important in higher precipitation zones, such as the Sacramento Valley where higher precipitation values do not always contribute to higher soil moisture storage for crop uptake.
  See Appendix D for additional information and references for estimating Pe.

- **Applied water (AW)** is the total volume of water that is applied to boundary (field, supplier, or basin) to meet the crop evapotranspiration, agronomic, and environmental use from any source, surface water (including tailwater reuse) or groundwater, public or private, including initial soil moisture in the soil profile that is not from precipitation. Unique values at each spatial scale include:
  - **Field scale applied water (AWf)** is quantity of water derived from supplier's surface or groundwater measured deliveries to the field (adjustments are needed if the entire delivery is not applied to the field) and private groundwater pumping within the field. Alternatively, AWf at the field may be measured with a water measurement device.

  - **Water supplier scale applied water (AWs)** is quantity of water derived from supplier's measured surface water diversions, surface water or groundwater deliveries to the supplier, and private groundwater pumping within the supplier's service area. Water used for Municipal and Industrial (M&I) and dairy production areas, etc. are excluded.
  - **Basin scale applied water (AWb)** is quantity of water derived from all supplier's measured surface water diversions, surface water or groundwater deliveries to the basin, and private groundwater pumping within the basin. Water used for M&I and dairy production areas, etc. are excluded.
  - **County scale applied water (AWc)** is quantity of water derived from suppliers and groundwater pumping within a county. This value may be estimated as described by the California Water Plan update (2009, and DWR staff personal communications). Water used for M&I and dairy production areas, etc. are excluded.

Method 2: Agronomic Water Use Fraction (AWUF). *Purpose:* It quantifies the efficiency of water use for the purpose of crop evapotranspiration and agronomic use. It allows for evaluation of the relationship between the consumptive use and agronomic uses of a crop and the quantity of water applied to an area. Method 2 is recommended for field, water supplier, and basin scales.

Method 2 allows for evaluation of the relationship between the agronomic use of a crop and the quantity of water applied to an area.

AWUF is calculated with the equation

Equation 2

$$\mathbf{AWUF = [ETAW+AU]/AW}$$

where AU is water needed to meet agronomic use in inches or acre-feet per year.

- **Agronomic use (AU)** is the portion of applied water directed to produce a desired agricultural commodity, such as water applied for salinity management or frost control, decomposition, and other water applications essential for production of crops.
  - **Leaching requirement (LR**) is the minimum leaching fraction (LF) that is required over a growing season for a particular quality of water to achieve maximum yield of a given crop (Letey et al., 2011). LF is the fraction of the total applied water that drains below the plant root zone. LR is used to estimate the amount of water needed to leach out excess salts from the root zone and create an optimum condition for crop production. It is the minimum LF that corresponds to the maximum salinity level that a specific crop can tolerate. LR is estimated using the ratio of the electrical conductivities of irrigation water and drainage water.

AWUF - agronomic water use fraction
AU - agronomic use
LF - leaching fraction
LR - leaching requirements

Equation 2-A

$$\mathbf{(LR= ECiw/ECdw)}$$

where ECiw is the electrical conductivity of irrigation water (decisiemens per meter-dS/m), and ECdw is the desired electrical conductivity of drainage water (dS/m) determined by salt tolerance of the crop. Decisiemens is a measure of electric conductance in a solution.

When measuring the electrical conductivity of drainage water is difficult, alternative methods can be utilized to estimate leaching requirement. Studies have shown, for example, that ECdw can be accurately estimated from the electrical conductivities of root zone saturation extract and irrigation water (Rhoades, 1974). According to Rhoades (1974),

The amount of water required to remove salts from the root zone area is estimated using the ratio of the electrical conductivities of irrigation water (ECiw) and desired drainage water ECdw.

LR = ECiw/ECdw

$$\mathbf{ECdw=5ECe\text{-}ECiw},$$

where ECe is the desired average electrical conductivity of the saturation extract in the root zone and ECiw is the electrical conductivity of irrigation water.

ECe can either be measured at different depths within the root zone, and average values calculated, or estimated from salinity tolerances of various crops. The Food and Agriculture Organization of the United Nations (FAO-UN) publication paper #29 (Ayers and Westcot, 1994) lists the salt tolerance data for various crops. ECe values can, therefore, be obtained from Table 4 of the FAO publication or other published works. Therefore, LR can be calculated from equation 2-B. See Table D-1 in Appendix D for crop salt tolerances and yield potential.

Equation 2-B

$$\mathbf{LR= ECiw /[(5ECe) – Eciw]}$$

where ECe is the crop salt tolerance threshold at no yield reduction.

Water in excess of the leaching requirement that goes to deep percolation would reduce water use efficiency at that scale. It should be noted, however, that due to uncertainties in quantifying leaching requirements and due to low distribution uniformities of applications, some amount of water in excess of leaching requirement may be reasonable.

- **Climate control** may require the use of some water for cooling of crops and frost protection. The amount of water used depends on crop type and weather parameters such as humidity and temperature. Application of water for climate control should start when temperature reaches critical thresholds for each crop and continued until the temperature becomes more favorable. Weather station networks such as CIMIS can provide the temperature and humidity data needed to determine when to turn sprinklers on and off. Although significant amount of water used for climate control may evaporate, the rest will infiltrate into the soil and become available for crops to consume. Currently, there are no standard procedures to estimate the amount of water needed for climate control and the portion of climate control water that will be consumed by plants. DWR recommends use of best professional practices in determining climate control use. DWR would develop guidelines for agronomic use in phase 2 of the implementation plan.
- **Crop seed germination** requires application of water that would evaporate from the soil surface. This evaporation of water should be included in the agronomic water use calculation**.**

Method 3: Total Water Use Fraction (TWUF). *Purpose:* This method quantifies the efficiency of water use to meet crop consumptive use, crop agronomic use, and environmental use. It considers the ratio of agronomic (AU) and environmental (EU) water use, in addition with ETAW, to the applied water. Method 3 is recommended for field, water supplier, and basin scales. TWUF is calculated with the equation:

Method 3 quantifies the efficiency of water use to meet crop consumptive use, crop agronomic use, and environmental use.

Equation 3

$$\mathbf{TWUF = [ETAW+AU+EU]/[AW]}$$

Where ETAW, AU, and AW are the same as defined above

- **Environmental use (EU)** is the portion of applied water directed to environmental purposes, including water to produce and/or maintain wetlands, riparian or terrestrial habitats. Applied water associated with a mandated environmental objective but ultimately used for ETAW or AU in the production of any agricultural commodity would be characterized as applied water for an environmental need. Currently, there is no clear standard for environmental water use or standard procedures for estimating EU, unless the EU is prescribed by regulation or permit conditions. Since no established standards exist for EU, the quantity of applied water estimated for intended EU is based on accepted professional practices. DWR will develop guidelines for environmental use during phase 2 of the implementation plan. EU is in units of inches per year or acre-feet per year.

Method 4: Water Management Fraction (WMF). *Purpose:* This method quantifies the efficiency of water management. Comparison of WMF and CCUF (calculated from Equation 1) within the same scale (supplier or basin) provides an opportunity to recognize that a portion of water that is applied by a water supplier or applied to a region for crop irrigation, but is not used by crops, may be recoverable flow (see example calculations in Appendix C). Method 4 is recommended for water supplier and basin scales and is calculated with:

Comparison of WMF and CCUF within the same scale provides an opportunity to recognize that a portion of water applied by a water supplier or applied to a region for crop irrigation, but not used by crops, may be recoverable flow.

Equation 4

$$\mathbf{WMF= (ETAW+ RF)/(AW)}$$

where **ETAW** and **AW** are defined as above and RF is in units of inches per year or acre-feet per year

- **Recoverable flow (RF)** is the amount of water leaving a given area as surface flows to non-saline bodies or percolation to usable groundwater that is available for supply or reuse. RF is calculated from surface return flows using gauge data and estimates of deep percolation while excluding evaporation and flows to salt sinks.

In regions where there is little recoverable flow (i.e., water exits the defined boundary to salt sinks or other unusable water bodies), the WMF would be closer to that calculated under Method 1, CCUF. Method 4 recognizes that unconsumed water may be useable elsewhere or at another time within the water management system.

Some components of the equations are empirical (measured or observed) and most of them are modeled (calculated/estimated).

The components of the methods used to quantify the efficiency of agricultural water use are either empirical (measured or observed) or modeled (calculated/estimated). Table 3-2 illustrates the empirical and modeled components of the four methods.

Table 3-2 Empirical and modeled components of the water use efficiency quantification methods

Method-scale	Equation	Empirical	Modeled
CCUF-basin	ETAW/AW		ETAW,AW,
AWUF-basin	[ETAW+AU]/AW		ETAW, AU,AW
TWUF- basin	[ETAW+AU+EU]/AW		ETAW, AU, EU,AW
WMF-basin	[ETAW+RF]/AW		ETAW, RF, AW
CCUF-supplier	ETAW/AW	AW	ETAW, AW
AWUF-supplier	[ETAW+AU]/AW	AW	ETAW, AU,AW
TWUF-supplier	[ETAW+AU+EU]/AW	AW, EU	ETAW,AU, EU,AW
WMF-supplier	[ETAW+RF]/AW	AW	ETAW, RF, AW
CCUF-field	ETAW/AW	AW	ETAW
AWUF-field	[ETAW+AU]/AW	AW	ETAW, AU,AW
TWUF-field	[ETAW+AU+EU]/AW	AW, EU	ETAW,AU,EU

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4 Plan of Implementation

Implementation schedule is contingent upon legislative authority and adequate funding.

The plan of implementation presented in this section describes an approach and identifies roles, implementing entities, data needs and sources, reporting, schedule/phasing, data management, and cost estimates that would be needed to implement the methodology (methods) proposed in this report for quantifying the efficiency of agricultural water use.

The legislation does not authorize implementation of this proposed methodology and does not identify sources of funding for its implementation. DWR recommends that if any of the methods proposed in this report are authorized for implementation, necessary sources of funding be identified and appropriated to support their implementation at the relevant spatial scales. In the implementation cost section, new funding needed for implementation is estimated.

4.1 Approach and Roles

It is proposed that the methodology be implemented using a phased approach.

Implementation would benefit from collaboration with the California Agricultural Water Management Council, agricultural water suppliers, academic and research institutions and California universities, and other cooperating agencies and organizations. DWR recommends that if the proposed methodology is implemented, that it be carried out using existing programs to the extent possible, and by expanding them, creating new programs, and/or reviving past programs as needed to avoid redundancy and reduce implementation costs. It is proposed that the methodology be implemented using a phased approach.

Existing programs may include (see Appendix A for selected sections of CWC):

- Agricultural water suppliers' preparation of agricultural water management plans (AWMPs) required by CWC §10820.
- Implementation of Efficient Water Management Practices required by CWC §10608.48.
- Agricultural water suppliers' reports of estimated efficiency improvements as required by CWC §10608.48 (d).
- Agricultural water suppliers reporting data as required by CWC §10608.48(e).
- Agricultural water suppliers aggregated farm-gate water delivery reporting per CWC §531.10.
- Preparation of the California Water Plan updates by DWR.

These existing legislative requirements provide a well-defined and convenient mechanism for the agricultural water suppliers to submit their calculations of the water use efficiency quantification methods to DWR. While CWC does not require water suppliers to quantify efficiency of agricultural water use or implement the proposed methodology, the agricultural water suppliers AWMPs may be used as a mechanism to report the results of calculations of the crop consumptive use fraction, agronomic water use fraction, total water use fraction, and water management fraction as well as the means and standard deviations of the on-farm (field scale) values of CCUF, AWUF, and TWUF within their service areas. DWR proposes that implementation of the proposed methodology be done by agricultural water suppliers as defined by the CWC 10608.12(a) (see Appendix A).

Agricultural water suppliers would report in their AWMPs their calculations of the four methods:
Method 1-CCUF – crop consumptive use fraction
Method 2-AWUF – agronomic water use fraction
Method 3-TWUF – total water use fraction
Method 4-WMF – water management fraction

Although Section 10608.64 of the California Water Code does not specify the implementing agency, DWR proposes that it would assume the following responsibilities, if and when the implementation is authorized and the necessary resources are provided. DWR would assume this role because it can provide consistency in implementation and can help in maintaining and disseminating the quantification of efficiency of agricultural water use information reported to it by the agricultural water suppliers or others.

- Develop a guidebook for consistent implementation of the methodology including refinements or improvements in data and procedures.
- Collect and maintain the data submitted to DWR in a database and disseminate the information in the California Water Plan update process.
- As DWR updates the Efficient Water Management Practices per CWC §10608.49(h), it would include the calculations of the above methods as a metric of reporting estimates of water use efficiency improvements by the agricultural water suppliers in their AWMPs.
- Provide coordination among entities involved in implementation of the proposed methodology.

4.2 Water Use Efficiency Quantification Methods

4.2.1 Water Supplier or Basin Scales

Implementation of the proposed methodology (Methods 1-4) would be responsibility of the agricultural water suppliers. Agricultural water suppliers optionally can form an alliance within a basin and implement the methodology.

A basin alliance is a group formed by two or more agricultural water suppliers within one watershed.

A basin alliance is a group formed by two or more agricultural water suppliers within one watershed. Watershed is defined as an area bounded by a perimeter where subsurface or surface flows drain to a single or multiple outlets serving the area. Basin may be positioned on one or more groundwater basins. Groundwater basin is defined as an alluvial aquifer or a stacked series of alluvial aquifers with reasonably well-defined boundaries in a lateral direction and having a definable bottom.

Basin Alliance. Agricultural water suppliers whose service area boundaries are within one watershed may form a partnership and apply the methodology for quantifying the efficiency of agricultural water use at the basin scale based on the following considerations:

- Agricultural water suppliers forming the basin alliance would formulate basin objectives demonstrating water use efficiency benefits gained by forming a basin alliance.
- The surface inflows into and outflows from the basin alliance boundary would be measured.
- Agricultural water suppliers would have water supply or drain water (surface or subsurface drainage) exchange across boundaries.
- The boundary of the basin may cross county boundaries.
- In general, agricultural water suppliers would belong to only one basin alliance for the purposes of establishing a partnership for implementation of the methodology for quantifying the efficiency of agricultural water use. In the case of tiered alliances, the larger alliance would include all of the individual water suppliers that belong to subordinate basin alliances.
- Individual agricultural water suppliers would apply the delivery fraction (note that DF is an indicator discussed in Chapter 5) to their respective service area.
- Basin-alliance individual agricultural water suppliers equal to or greater than 25,000 acres (and greater than 10,000 acres but less than 25,000 acres if funding is available) would calculate CCUF, AWUF, TWUF, and to the extent possible WMF and report for their individual service areas.

Water suppliers greater than 25,000 irrigated acres are already required to prepare AWMPs, implement EWMPs, and report efficiency improvements in the AWMPs as required by CWC §10608.48 (d)

4.2.1.1 Data Needed to Support the Methodology

Data needed to support the methodology at this scale include reference evapotranspiration, crop coefficient, effective precipitation, land use data, crop types, irrigated acreage, water use data including water supplies entering the supplier's Distribution System (WS), applied water, agronomic use, environmental use, recoverable flow, and any storage or depletion from the supplier reservoirs. Timescale for computation of the crop consumptive use fraction, agronomic water use fraction, total water use fraction, and water management fraction at the supplier scale is yearly based on annual values of the components of these equations for the supplier (annual Evapotranspiration of Applied Water, AW, EU, AU, and WS).

If water suppliers provide on-farm evaluation, as described by CWC §10608.48, a statistical analysis is recommended using a mathematically accepted approach toward achieving a science-based outcome. In this approach, one would determine a statistical mean and standard deviation of field efficiency within a supplier area or basin. This would require a random sample at that would represent irrigation system types in order for the assessment to be statistically

AU – agronomic use
AW – applied water
AWUF – agronomic water use fraction
CCUF – crop consumptive use fraction
ETAW – Evapotranspiration of Applied Water
ETo – reference evapotranspiration
EU – environmental use
Kc – crop coefficient
Pe – effective precipitation
RF – recoverable flow
TWUF – total water use fraction
WMF – water management fraction
WS – water supply

sound. The evaluation could be achieved by utilizing on-farm evaluation by mobile labs after modification to the existing mobile lab protocols.

4.2.1.2 Data Sources, Quality, and Limitations

The quality of existing data needed to implement the methodology varies significantly from supplier to supplier and across data categories. This presents the largest challenge to generating useful information from the methodology. Some data are measured with a high degree of accuracy; some at a lower accuracy; and some important data are currently not measured and would be estimated. Table 4-1 provides a summary of data needed, likely sources of data for supplier level methods, and identifies options, recommends an option and needed improvements.

Data needed for basin alliance scale is as follows: Each participating supplier's values of ETAW, AW, AU, EU, (and RF if available) and basin alliance scale values of ETAW, AW, AU, EU, and RF (from the boundaries of the basin alliance).

4.2.1.3 Data Collection and Reporting Responsibility

Data collection at the water supplier scale is the responsibility of the agricultural water suppliers required to prepare and submit agricultural water management plans. Water suppliers would report annually the data they gather and report in their AWMPs every five years. Agricultural water suppliers subject to the water management planning provisions of SB X7-7 (greater than 25,000 irrigated acres, and between 10,000 and 25,000 irrigated acres if sufficient funding is provided) would already be providing in their AWMPs some of the information, which are needed to support the methodology. This information is required under CWC §531.10 and §10608.48 and identified in Table 4-1. See also Box 4-1. The agricultural water suppliers would include the data, assumptions, and results of quantification of CCUF, AWUF, TWUF, and WMF at the supplier scale and summary of the field scale CCUF, AWUF, and TWUF in their agricultural water management plans. DWR would include the summary of water supplier scale field scale values in the CWP update.

Table 4-1 Water supplier data needed, data sources, and options for quantifying the efficiency of agricultural water use

<table>
<tr><th></th><th>Data needed</th><th>Source of data/options</th><th>Notes</th></tr>
<tr><td rowspan="5">Crop ET and ETAW</td><td>Crop area</td><td>Water supplier records</td><td rowspan="5">Water suppliers equal or greater than 25,000 acres, are required by CWC 10826 (b) to describe the quantity of water use in the service area.</td></tr>
<tr><td>Pe</td><td>Calculated from precipitation data from CIMIS or equivalent source</td></tr>
<tr><td>Kc</td><td>CIMIS or equivalent</td></tr>
<tr><td>Crop ET</td><td>Calculated using CIMIS Eto and Kc or equivalent source based on water supplier scale or aggregate from field scale data, or calculated from processed satellite imagery</td></tr>
<tr><td>ETAW</td><td>Calculated (from Etc and Pe) based on water supplier scale, aggregate from field scale data, or from processed satellite imagery</td></tr>
<tr><td rowspan="3">Applied Water (AW)</td><td>Surface diversions or surface water deliveries to the water supplier</td><td>Water supplier records or private water rights diversions from aggregated farm-gate deliveries</td><td rowspan="2">Water suppliers equal or greater than 25,000 acres measure deliveries CWC 10826(b)(7)(A). Water suppliers less than 25,000 but greater than 10,000 if funding is available, CWC 10853. Water suppliers greater than 2,000 acres report aggregated farm-gate deliveries to DWR, CWC 531.10.</td></tr>
<tr><td>Groundwater deliveries</td><td>Water supplier records or groundwater use records, estimates from modeling</td></tr>
<tr><td>Private groundwater use</td><td>Private groundwater use data, estimates from power use, estimated by modeling</td><td>Groundwater use may be unmeasured</td></tr>
<tr><td rowspan="3">Agronomic use (AU)</td><td>Leaching requirement</td><td>Calculated at the supplier scale from equations in this report or use best professional practices or aggregated from field scale values</td><td rowspan="3">Water suppliers equal or greater than 25,000 acres are required by CWC 10826 (b) to quantity overall water budget and tabulate water uses. Water suppliers greater than 10,000 and less than 25,000 if funding is available.</td></tr>
<tr><td>Climate control</td><td>Use best professional practices.
DWR may develop guidelines or methods in phase 2.</td></tr>
<tr><td>Others</td><td>Seed bed preparation etc. Use best professional practices (BPP)</td></tr>
<tr><td rowspan="2">Environmental Use (EU)</td><td>Water dedicated to environmental purposes (by regulation or permit)</td><td>Actual environmental water use required by regulation</td><td rowspan="2">Water suppliers equal or greater than 25,000 acres, CWC 10826 (b) to describe the quantity of water uses including environmental uses. Water suppliers greater than 10,000 and less than 25,000 if funding is available, CWC 10853.</td></tr>
<tr><td>Additional water provided for environmental purposes</td><td>Studies or data collected from fields</td></tr>
<tr><td rowspan="2">Recoverable Flow (RF)</td><td>Surface drainage</td><td>Actual surface outflow measured from water supplier or basin boundaries</td><td rowspan="2">Suppliers equal or greater than 25,000 acres, CWC 10826 (b) (6) and (7)(C) to quantity drainage & water budget, Water suppliers greater than 10,000 and less than 25,000 if funding is available, CWC 10853].</td></tr>
<tr><td>Deep percolation (drainage)</td><td>Estimated by modeling</td></tr>
</table>

Acronyms: Pe – effective precipitation , CIMIS – California Irrigation Management Information System, Kc – crop coefficient, ETo – reference evapotranspiration, ET – crop evapotranspiration, ETAW – Evapotranspiration of Applied Water. BPP- Best Professional Practices.

Box 4-1 A Brief Description of Reporting Requirements under the Statutes

Agricultural Water Management Plan (AWMP) and Efficient Water Management Practices (EWMPs) Reporting

AWMPs per SB X7-7 Chapter 3 Article 1 10820 (a) states that an agricultural water supplier shall prepare and adopt an agricultural water management plan on or before December 31, 2012, and shall update that plan by December 31, 2015, and on or by December 31 every five years thereafter. These plans are to be submitted to the DWR.

Agricultural Water Measurement Regulation

Subdivision 10608.48(a) of SB X7-7 sets July 31, 2012 as the date by which agricultural water suppliers shall implement EWMPs that include measuring the volume of water delivered to customers.

Furthermore; Section 531.10(a) of the California Water Code (CWC), requires that:

(a) An agricultural water supplier shall submit an annual report to the department that summarizes aggregated farm-gate delivery data, on a monthly or bi-monthly basis, using best professional practices.

Agricultural water suppliers providing water to less than 10,000 irrigated acres, excluding acres that receive only recycled water are not subject to the water measurement regulation. They remain subject to reporting requirements of Section 531.10 of the Water Code if they deliver more than 2000 acre feet of water or irrigate 2000 or more acres of land, and if water measurement is locally cost effective. The schedule of submittal of the farm-gate delivery is on an annual basis and are due starting July 30, 2013.

Agricultural water suppliers providing water to 10,000 or more irrigated acres but less than 25,000 irrigated acres, excluding acres that receive only recycled water, are not required to implement the water measurement requirements unless sufficient funding is provided specifically for that purpose, CWC 10853.

Agricultural water suppliers providing water to 25,000 irrigated acres or more, excluding acres that receive only recycled water, shall measure water deliveries consistent with the water measurement regulation.

4.2.1.4 Schedule of Implementation

A phased implementation approach is recommended to allow the use of existing data to prepare initial calculation of the supplier level methods while data improvements are identified for implementation in subsequent phases.

Water suppliers report in AWMP the mean and standard deviation of field scale methods and distribution uniformity values in their service area.

Phase 1: Initial implementation, the first AWMP after legislative authority and source of funding are established

- Suppliers with existing data to make initial calculations of methods and include in their AWMPs. Some or most suppliers would have relatively good existing data on delivery records estimates of private groundwater pumping, agronomic uses, environmental uses and operational spill.
- DWR in cooperation with stakeholders identify any data improvements needed to implement the proposed methodology.
- DWR and cooperators set priorities for improvements. Priorities could be based on data components (e.g., agronomic uses and environmental uses) and based on statewide or basin water management considerations.
- DWR develops a plan to improve the key limiting data for phase 2, based on expected costs or on a range of potential costs and available funds.
- Pending availability of funding, DWR develops programs and identifies or proposes sources of financial support for suppliers smaller than 25,000 acre to prepare AWMPs and calculate the methods.
- DWR develops data management program to collect, maintain, and disseminate the data.

Phase 2: Data improvements, the second AWMP after legislative authority and source of funding are established

- Suppliers implement the data improvement and apply the methods using the improved data. The suppliers report results in their AWMPs.
- DWR, cooperating entities and suppliers, and other experts assess results and revise data improvement recommendations, if necessary.

Phase 3: Full Implementation, the third AWMP after legislative authority and source of funding are established

- All suppliers implement any data improvement from phase 2, calculate supplier-level methods, and report to DWR in AWMPs.

4.2.2 Field Scale

4.2.2.1 Data Needed to Support the Methodology

The field scale methods use data collected from individual fields or categories of individual fields. Categories can be defined by basin, crop type, irrigation system, soil type, and other factors. Data needed at this scale are ETo, Kc (not needed with energy balance methods), effective precipitation, water quality, agronomic water use, environmental use, and applied water. Timescale for computation of DU (see Section 5 - Indicators) at the field scale is per event; timescale for CCUF, AWUF, and TWUF is annual (or growing season) and determined based on annual values of ETAW, AW, AU and EU.

Field scale methods and distribution uniformity indicator are recommended for implementation by water suppliers, government agencies, and other interested entities for participating growers.

4.2.2.2 Data Sources, Quality, and Limitations

Quantification of field scale water use efficiency must rely on grower-supplied data, data gathered during voluntary field scale studies, or new data gathered from field scale measurements such as through irrigation evaluations. Growers often measure and use information on applied water, crop water use, soil moisture, distribution uniformity, and return flow. They use these data to manage irrigation and production and to understand and control costs. They generally do not provide this information to others. There is a wide variation in the techniques used to measure or estimate field scale water use.

DWR is working on a project with NASA that may be able to assist in calculating CCUF at the field scale via a model that is under development. This would provide estimated values of crop specific evapotranspiration that would be very useful for planning and management but would still require some undetermined amount of ground truthing by whoever uses the product.

The availability and quality of field scale water use data vary significantly. Some data are measured with a high degree of accuracy by some growers but with a lower accuracy by others. Some growers may calculate crop ET, and some may keep track of water applied for specific agronomic uses. Environmental uses of water that are incidental to crop irrigation activities would generally not be monitored or estimated by growers, whereas water applied specifically for environmental uses (such as winter field flooding for waterfowl) might be recorded.

Field scale water applications include water delivered to the field by the water supplier, groundwater pumped from private wells, and water reused from other fields (if it has not been delivered through the supplier’s system). Many water suppliers maintain records of their water deliveries by field, but may not record the crop grown or the planting and harvest dates. Other water supplier’s measure and record deliveries to turnouts (upstream of point of delivery to many fields) but not necessarily to individual fields. Growers view individual field records as proprietary business information, and suppliers do not release information by field, though some could provide aggregated data by crop. For most irrigated lands in California, private groundwater use on fields is recorded only by the growers. On-farm reuse of water would be recorded if done by the grower.

Table 4-2 provides a summary of data needed, likely sources of data for field methods.

Table 4-2 Field scale list of data needed, data sources, and options for quantifying the efficiency of ag water use

	Data needed	Source of data/options	Notes
Crop ET and ETAW	Crop area	Growers records	---
	Pe	Calculated from precipitation data from CIMIS or equivalent	---
	Kc	CIMIS or equivalent source	---
	ET	Calculated using CIMIS Eto and Kc or equivalent or calculated from processed satellite imagery	---
	ETAW	calculated (from Etc and Pe) based on field scale data, or calculated from processed satellite imagery	---
Applied Water (AW)	Surface diversions or surface water deliveries to the water supplier	Water supplier records or field measurement during evaluation or measure water diversions	Water suppliers greater than 25,000 measure delivery CWC §10608.48(b)(1) and for suppliers more than 10,000 acres if funding is available CWC 10853. Water suppliers equal or greater than 2,000 acres are required by CWC §531.10 to report aggregated farm-gate deliveries to DWR.
	Groundwater deliveries	Water supplier records	
	Private groundwater use	Private groundwater use data, estimates from power use, measured, estimated by modeling	Groundwater use may be unmeasured
Agronomic use	Leaching requirement	Calculated from equations in this report or use best professional practices (BPP)	---
	Climate control	Use BPP	DWR may develop guidelines or methods in future
	Others	Seed bed preparation etc. Use BPP	---
Environmental Use	Water dedicated to environmental purposes (by regulation or permit)	Actual environmental water use required by regulation	May be required by permits or regulations
	Additional water provided for environmental purposes	Studies or data collected from field evaluation, growers records,	DWR may develop guidelines or methods in future

Acronyms: Pe – effective precipitation , CIMIS – California Irrigation Management Information System, Kc – crop coefficient, ETo – reference evapotranspiration, ET – crop evapotranspiration, ETAW – Evapotranspiration of Applied Water. BPP- Best Professional Practices.

4.2.2.3 Data Collection and Reporting Responsibility

DWR recommends that the field scale methods be implemented through a co-operative and voluntary irrigation evaluation program of self-enrolled growers. For suppliers equal or greater than 25,000 acres, field scale evaluations and calculations would be done through the on-farm irrigation evaluation programs that water supplier provides to its customers (as described by CWC section 10608.48 (d), if it is locally cost effective).

Mobile labs (teams of technicians with specialized equipment to perform irrigation evaluation) were established in California to perform activities such as DU and onsite irrigation system evaluation for efficiency. The evaluation takes one day to complete, covers an entire field evaluated, and includes standardized data collection and analysis. The primary field activities for evaluating DU and system efficiency are pressure measurements, flow rate measurements, and the determination of applied water for a specific irrigation event.

- On-farm evaluation service would be provided, on a voluntary basis, to growers, in a representative sample of fields by region, crop, irrigation system, and other appropriate factors. The data collected would be provided to the growers for making improvements in their water management practices. DWR has in the past funded irrigation system evaluation on a cost share arrangement with water suppliers. This can be a phased approach starting with supporting the existing irrigation system evaluations and potentially expanding to additional irrigation system evaluations (through mobile labs or similar venues) to provide a larger and more representative sample of fields. Mobile lab protocols need to be significantly modified to accommodate implementation of the methods 1-3 beyond the simpler measurements needed for distribution uniformity (discussed in Section 5). Protocols for confidentiality would be developed to ensure that information identifying individual fields, owners, or operators is not improperly disclosed. Collected data stripped of any personal or business information would be used by participating local and State agencies for improving local, regional, and statewide water management planning.
- Water suppliers and participating agencies develop summary of data including mean and standard deviation of field scale values of CCUF, AWUF, and TWUF and submit to DWR in AWMP.
- Existing Natural Resources Conservation Service (NRCS) and California Association of Resource Conservation Districts (CARCD) protocols for the irrigation system evaluation (mobile lab) activities be utilized.

For suppliers smaller than 25,000 acres, field scale evaluations would be done by water supplier or other cooperating entities if funding is available. DWR recommends:

- A cost share program in cooperation with interested entities. Potential entities may include the Agricultural Water Management Council, water suppliers, cooperating federal agencies, California Resource Conservation Districts, University of California Cooperative Extension, and other research institutions such as Cal Poly Training and Research Center or the Center for Irrigation Technology at California State University, Fresno, or other entities to provide an irrigation and water use evaluation service, modeled on the irrigation system evaluation, to cooperating growers.

4.2.2.4 Schedule of Implementation

DWR recommends that implementation of the field methods occurs in phases. An initial assessment is needed that collects and assesses the existing data and develops priorities for the collection of improved field data. Representative samples of fields would be selected based on the priorities, available resources, and growers' willingness to participate. Water suppliers implement methods 1, 2, and 3 based on existing data at the field scale. The second phase would focus on new estimates, using detailed field evaluations that include estimates of irrigation system performance. Resources would be allocated according to the priorities developed in phase 1. DWR would revise and improve upon data or procedures, if needed. The data improvement can be scaled to match resources available by adjusting the sample size of fields evaluated and by narrowing or broadening the number of priorities. Quantification methods could be applied and updated on a regular basis during this phase. DWR would refine the methods and protocols as needed. Phase 3 is full implementation.

Phase 1: Initial Quantification, the first AWMP after legislative authority and source of funding are established

- Water suppliers greater than or equal to 25,000 acres include in AWMP any on-farm evaluations and make initial calculation of field scale water use efficiency quantification methods based on the past practices. Develop a plan for providing on-farm irrigation evaluation, if locally cost effective.
- Water suppliers smaller than 25,000 acres include in AWMP any irrigation system evaluation evaluations and make initial calculation of field scale water use efficiency quantification methods based on the past practices if funding is made available.
- Based on review of AWMP, DWR in cooperation with stakeholders would identify data improvements or needed improvements in procedures to implement the methodology.
- DWR and cooperators identify important data needs develop procedures priorities for improvements. Priorities would be based on data components (e.g., field scale ET estimates versus water applied versus agronomic uses), crop categories, basins, irrigation methods, or other factors. Priorities would also be based on statewide or basin water management considerations.
- Water suppliers develop a plan to improve the key limiting data. Based on expected budget or on a range of potential budgets, develop a sampling plan to identify representative numbers of fields according to the priorities.

Phase 2: Data Improvements, the second AWMP after legislative authority and source of funding are established

- Water suppliers greater than 25,000 acres, if locally cost effective, provide field evaluations for implementation of field scale methods and implement the phase 1 plans and report in AWMPs.
- Based on priorities and available funding, DWR and cooperating agencies implement the data improvement recommendations from phase 1.
- Water suppliers calculate methods and update regularly as improved data is collected.
- Pending availability of funding, DWR develops programs and identify or propose sources of financial support for on-farm irrigation evaluation for suppliers smaller than 25,000 acre.

Phase 3: Full Implementation, the third AWMP after legislative authority and source of funding are established

- For water suppliers greater than 25, 000 acres implement if locally cost effective and for suppliers smaller than 25,000 acres implement if funding is available. As appropriate apply improved data collection and estimation processes and implement methods. An ongoing voluntary field sampling program would be part of this phase.

4.3 Reporting the Quantification of Efficiency of Agricultural Water Use

Data used and the results of the quantifying of the efficiency of agricultural water use would be reported as described in Table 4-3.

Table 4-3 Data elements, schedule, and responsible entity reports

Data element	Schedule	Responsible entity report
Statewide scale		
Summary of data reported in the AWMP to DWR.	California Water Plan updates after the legislative authority and sources of funding are established	California Water Plan updates
Supplier / basin alliance scale		
Basin alliance scale values of CCUF, AWUF, TWUF, and WMF. Supplier scale values of ET, Pe, ETAW, Kc, AW, AU (including LR, climate control, seed germination, etc.), EU, RF, WS, FGD, TWS, CCUF, AWUF,TWUF, WMF,(and indicator DF), mean and standard deviation of field scale CCUF, AWUF, TWUF, and indicator DUs (See Section 5)	AWMPs, after legislative authority is established. AWMPs for suppliers less than 25,000 acres after the legislative authority and sources of funding are established	Agricultural Water Supplier's Agricultural Water Management Plan. Suppliers report field data in summarized form.

4.4 Data Management

DWR recommends that the results of the quantification of efficiency of agricultural water use when submitted to DWR be maintained by DWR and disseminated through the California Water Plan updates and other DWR planning and educational documents. CWC requires DWR to develop a standardized data reporting form that water suppliers may use to submit water use data to agencies. DWR would maintain these data in a water use database that is being developed by DWR.

4.5 Estimated Implementation Costs

The implementation costs are estimated for both DWR and for the local suppliers and growers. The split of local costs between suppliers and growers could vary significantly across regions, so is not specified in this estimate. DWR's estimate of its costs of carrying out its roles and responsibilities for implementation of the recommendations of this report is based on past budget planning experience.

For estimating local costs, DWR has developed a list of agricultural water suppliers and the irrigated acreage of each supplier. DWR has also made an estimate of costs of installing and operating and maintaining water measurement devices as required by water measurement regulation (DWR, 2011). The costs described below are present value for 20-year for implementation of the methodology when they would be fully implemented with seven-year life-time for equipments. It is not for any particular phase of implementation.

Summary of Implementation Costs

The proposed plan of implementation would require new funding for DWR and water suppliers. These costs are summarized below and described in this section.

DWR costs

The cost to DWR to support implementation of the proposed methodology is about $400,000 per year in addition to one a time cost of $500,000 for developing a database.

Costs to water suppliers equal or greater than 25,000 acres

For estimating new costs, it is assumed that all water suppliers equal to or greater than 25,000 acres irrigated land are measuring water deliveries and reporting water use information in AWMPs, in accordance to the CWC requirements. The total cost for implementation of the four methods to these water suppliers, for a total of 6 million acres irrigated lands, would be about $6 million to $30 million per year.

Costs to water suppliers greater than 10,000 and less than 25,000 acres

For estimating new costs, it is assumed that all water suppliers greater than 10,000 and less than 25,000 acres (1) are not measuring water deliveries, (2) and water use information is not collected (CWC requires this category of suppliers to measure and report if funding is available). Therefore, the measurement of deliveries and water use information would have new costs to these water suppliers. The total costs to these water suppliers, for a total of 757,000 acres of irrigated land, would be about $8.8 million per year and a one-time cost of $15 million for installing water measurement devices.

Costs to water suppliers with 25,000 acres or greater for implementing field scale methods

In the proposed methodology, field scale methods would be voluntary, and a water supplier would select a representative sample of participating fields for field scale implementation. The total cost to a water supplier with 25,000 acres or greater (with 300 fields) for computing methods 1, 2 and 3 for field scale (assuming it is applied to 75 sites) is about $12,500 to $31,000 per year. Water delivery measurement to fields is required by CWC; therefore, no water measurement cost is included. If all the 75 fields are supplied by private groundwater that is not measured or estimated, the cost of groundwater measurement would be about $150,000 ($24/site) plus $50,000 per year ($8/acre/year).

4.5.1 General Data and Improvement Costs

DWR would assist water suppliers by developing guidelines or making improvements in data and procedures for implementing the methodology, if needed. The approximate cost for DWR of developing guidelines and improvements in the methodology is estimated to be $100,000 per year.

Data standards and the improvement plan would primarily be based on existing DWR and other established programs such as the Water Plan update data collection and water balance calculations, agricultural water measurement and diversion reporting, and water supplier field scale water use evaluation activities

Data Reporting Costs

Although the cost estimate will be determined as if DWR were reporting and disseminating the information, other possible candidates could include UC Cooperative Extension, other universities and research institutions, private consultants, etc. Most associated costs will be dependent upon the activities and the responsible entity. The approximate cost of disseminating data is $100,000 per year.

Data Management Costs

The development of a standardized water use reporting database is essential to the successful outcome of online water use and water management plan submittal. DWR's capital outlay for this project would be approximately $500,000 with annual operation and maintenance and data management costs of approximately $200,000. DWR's spatial CIMIS project already provides reference evapotranspiration statewide and is in the process of developing a complementary map of crop coefficients, which when combined would provide crop specific evapotranspiration at a 2-kilometer resolution. Although the CIMIS capital outlay has already been established, it is anticipated that additional funds would be needed for annual operations and maintenance.

4.5.2 Water Supplier Scale Costs

Water suppliers would implement the four methods, CCUF, AWUF, TWUF, and WMF. To implement these methods annually the water supplier needs to quantify the annual values (as applicable) of the following parameters and perform the following (for details see Table 4-1 and Table 4-4, which appears at the end of this section):

1. Measure applied water to agricultural lands.
2. Measure or estimate private groundwater used for irrigation in its service area.
3. Measure tailwater from irrigation flowing out its service area.
4. Collect crop information including crop area, length of crop season, root depth, crop Kc values, and crop ET.
5. Estimate effective precipitation.
6. Calculate ETAW.
7. Calculate leaching and other climatic control water use in its service area.
8. Calculate CCUF, AWUF, TWUF, and WMF.
9. Water suppliers of 25,000 acres or more of irrigated land are required to report components of the CCUF, AWUF, TWUF, and WMF in their AWMPs. Therefore, items 1 through 7 are already quantified per CWC (Table 4-1 describes the current requirements). Assuming that these water suppliers would already quantify the various parameters needed for computation of the four methods, the average annual cost of data collection associated with computation of CCUF, AWUF, TWUF, DF (Note DF is an Indicator - and farm gate delivery (FGD) and water supply (WS) are reported by these suppliers), and WMF for these suppliers is estimated to be $1 to $5 per acre. Upper range cost would be associated with those agencies that do not currently have data collection activities and have more varied and complex cropping patterns and water supply and distribution systems while the lower costs would be associated with the majority of agencies that have a data collection program and less varied and complex crop and water systems.

Field scale values of CCUF, AWUF, DU (note DU is an Indicator and is discussed in Section 5), and TWUF would be statistically calculated over the entire supplier’s service area based on the mean and standard deviation of available field scale calculated values, if supplier provides on-farm evaluation of irrigation systems (cost of field scale evaluations and data analysis are presented in Field Scale Costs section 4.5.3).

For water suppliers with irrigated acreage equal or greater than 25,000 acres;

1) DWR estimates that there are about 77 water suppliers in this size category, with 6 million acres of irrigated land (Table 3-1).
    a) The water suppliers in this size category are required to measure water deliveries so no new cost is estimated.
    b) It is assumed that computation of methods 1 through 4 for this category of water suppliers will cost about $1 to $5 per acre per year. This cost is based on DWR personal communication with consultants who prepare water management plans.
2) Estimated total costs for all water suppliers in this size category ranges from $6 million to $30 million per year.

For suppliers serving more than 10,000 acres but less than 25,000 acres, additional measurement devices may be required to effectively calculate the four methods (Tables 4-1 and 4-4). Existing legislation requires collection of some data if funding is available. About 50 water suppliers serve less than 25,000 acres but more than 10,000 acres, comprising a total 0.757 million acres (see Table 3-1). Twenty of these suppliers (316,000 acres) are Central Valley Project contractors that measure water delivery to their customers so no new costs are expected for water measurement. The remaining 30 non-federal water suppliers (440,000 acres) may need to install water measurement devices to measure deliveries. The initial cost of installing a device is estimated to be $24 per acre and annual ongoing cost of $8 per acre for a total of $10.5 million plus $3.5 million per year. The costs of water measurement device are based on DWR's estimate for agricultural water measurement regulation (DWR, 2011). Additionally, all 757,000 acres suppliers need to calculate CCUF, AWUF, and TWUF and DF and WMF at the supplier scale. The annual cost of data collection associated with computation of CCUF, TWUF, DF, and WMF for these suppliers is estimated to be $2 to $5 per acre/year for a total cost of $1.5 to $3.8 million per year. These suppliers (757,000 acres) may also have to measure drainage flows (tail water or tile water). It is also assumed that if the water supplier has recoverable flows, it amounts to 25% of its deliveries and the cost of measurement is $6/acre plus $2 /acre/year for a total cost of $4.5 million plus $1.5 million per year. The suppliers are also calculating mean and standard deviation of field scale values. The costs are included in the Field Scale Costs (section 4.5.3).

CWC 10853 requires water suppliers greater than 10,000 acres to measure water deliveries (for 10,000 to 25,000 acres only if funding is available), Water suppliers less than 10,000 and greater than 2,000 acres are subject to CWC §531.10 water deliveries reporting.

Total cost for water suppliers greater than 10,000 and less than 25,000 acres is $15 million plus $8.8 million per year.

The Costs of implementation of a basin alliance is not included because its costs will vary depending on the number of suppliers joining the basin-alliance and the characteristics of the individual water suppliers. However, the cost of implementation is expected to be less than the sum of the costs of individual participating water suppliers.

For water suppliers with irrigated acreage between 10,000 and 24,999 acres;

1) DWR estimated that there are about 50 water suppliers in this size category with 757,000 acres of irrigated lands.
   a) The cost of water measurement and quantifying other water use information is estimated to be $24 per acre plus $8 per acre per year for O&M for a total cost of $19 million plus $6 million per year for O&M.
   b) The cost of water measurement devices for measuring recoverable flows (assumed to be about 25% of deliveries) is estimated to be $6 per acre plus $2 per acre per year for O&M for a total cost of $5 million plus $2 million per year for O&M.
   c) It is assumed that computation of methods 1 through 4 for this category of water suppliers will cost about $2 to $5 per acre per year for a total cost of $1.6 million to $4 million per year. This cost is based on DWR personal communication with consultants who prepare water management plans.
2) Estimated total cost for this size category is about $6 million per year in addition to an initial cost of $24 million for water measurement installation**.**

4.5.3 Field Scale Costs

It is recommended that the field scale methods be conducted for participating growers. Water suppliers or other cooperating entities would implement three methods, CCUF, AWUF, and TWUF. To implement these methods annually the program needs to quantify the annual values (as applicable) of the following parameters and perform the following tasks (for details see Table 4-1 and Table 4-4):

1. Measure applied water to the field.
2. Measure or estimate private groundwater used for irrigation.
3. Collect crop information including crop area, length of crop season, root depth, crop Kc values, and crop ET.
4. Estimate effective precipitation (may use CIMIS).
5. Calculate ETAW.
6. Calculate leaching, seed germination water use, and other climatic control water use.
7. Calculate CCUF, AWUF, and TWUF.

8. For water suppliers that offer on-farm irrigation evaluation, DU is also determined.

The field scale costs are estimated for a 25,000-acres water supplier. Assuming a field size of 83 acres, the total number of sites in the supplier area would be 75. Field size could vary which affects the cost of measurement of flows. The cost descriptions of the above tasks are as follows:

1. Applied surface and groundwater water is measured and has no new cost (CWC §10608.48(b)(1) and 10853).
2. Private groundwater (if applicable) may be measured at a cost of \$24/acre and \$8/acre/year or estimated using power usage data.
3. Items 3 through 8 above is estimated to cost about \$2 to \$5/acre/year

For field scale methods in a water supplier with 25,000 irrigated land;

1) Application of field scale methods is not required on all fields within a water supplier service area; rather the water supplier will select representative fields for implementation. For the purpose of estimating costs, it is assumed that a water supplier with 25,000 acres irrigated land (300 fields of 83 acres) would apply the field scale methods on 75 fields.
    a) It is assumed that computation of methods 1 through 3 for field scale including calculation of DU (see Section 5) will cost about \$2 to \$5 per acre per year. This cost is based on DWR personal communication with consultants who prepare water management plans.
    b) For water suppliers 25,000 acres water delivery to fields is required, so no new cost is estimated.
2) Total cost to a water supplier for computation of methods 1 to 3 for field scale (assuming it is applied to 75 sites) is \$12,500 to \$31,000 per year. If all the75 fields are supplied by private groundwater that is not measured or estimated, the cost of groundwater measurement will be \$150,000 (\$24/site) plus \$50,000 per year (\$8/acre/year).

Table 4-4 Estimated cost of implementing the proposed methodology

Cost category	Data needed	Cost of supplier scale for: Suppliers equal to or greater than 25,000 acres	Cost of supplier scale for: Suppliers more than 10,000 and less than 25,000 acres	Cost of field scale for suppliers (estimate is for 75 fields in a water supplier with 25,000 acres irrigated land)	DWR annual costs
Crop ET and ETAW	Crop area Pe Kc Crop ET ETAW	Required of water suppliers equal to or greater than 25,000 acres, CWC §10826 (b)(7)(C) for a total of about 6 million acres	$2-5/acre/year for 757,640 acres	$2-5/acre/year for 75 sites 83 acres each (6,225 acres)	Not Applicable (NA)
Applied Water (AW)	Surface diversions or surface water deliveries to the water supplier boundary Groundwater deliveries	Required of water suppliers equal to or greater than 25,000 acres, §10826(b)(7)(A).	Required of water suppliers greater than 10,000 and less than 25,000 acres if funding is available §10826(b)(7)(A). $24/acre for 442,000 acres (non-federal suppliers) plus $8/acre/year if applicable, $10.6 m plus $3.5 m/year	Required of water suppliers equal or greater than 25,000 acres and for 10,000 to 25,000 if funding is available §10608.48(b)(1)	NA
	Private groundwater use	Groundwater use may be unmeasured, has to be estimated. Included in Calculation of Efficiency Methods Costs	Included in ET and ETAW Costs	($24*/acre if applicable)	
Agronomic use (AU)	Leaching Requirement Climate control Seed germination (if applicable)	Required of water suppliers equal to or greater than 25,000 acres, CWC §10826 (b)	Included in crop ET and ETAW costs	Included in crop ET and ETAW costs	NA

Table 4-4 (cont'd.) Estimated cost of implementing the proposed methodology

Cost category		Data needed	Cost of supplier scale for: Suppliers equal or greater than 25,000 acres	Cost of supplier scale for: Suppliers more than 10,000 and less than 25,000 acres	Cost of field scale for suppliers (estimate is for 75 fields in a water supplier with 25,000 acres irrigated land)	
Environmental Use (EU)		Water dedicated to the environmental purposes	Required of water suppliers equal or greater than 25,000 acres, CWC §10826 (b)	If required by regulation, it is already measured	Included in crop ET and ETAW costs	NA
		Other		Included in recoverable flow costs	-	
Recoverable Flow (RF)		Surface drainage	Required of water suppliers equal or greater than 25,000 acres, CWC §10826 (b) (6) and (7)(C)	$6*/acre plus $2/acre/year for 758,000 acres, cost $4.5 m plus $1.5 m/year	NA	NA
		Deep percolation (drainage)				
Calculation of Efficiency Methods		CCUF, AWUF, TWUF, WMF	$1-5/acre/year for 6 million acres	Included in Crop ET and ETAW Costs	Included in ET and ETAW costs	NA
Data management		Data collection/Management/reporting			NA	$300,000**
Improvements		Data/Procedure Improvements	NA	NA	NA	$100,000
		Total (new costs)	$1-5/acre/year or a total of $6 million to $30 million per year.	Combined costs $15 million plus $6.5 to $8.8 million /year#	$2-5/acre/year or $12,500 to $31,000 per year for 75 sites	$400,000

*- cost of water measurement device for recoverable flows and associated tasks.

**- additionally, DWR would have a one-time cost of $500,000 for database development.

#- combined cost of AW, RF, and data collection and measurement.

5 Supplemental Indicators

In addition to the four proposed methods for quantifying the efficiency of agricultural water use, DWR has included in this report four indicators that would provide supplemental information about irrigation system performance and crop productivity. These four indicators do not quantify the efficiency of agricultural water use. The purpose and application of these indicators are described in this section and summarized in Table 5-1.

Table 5-1 Proposed implementing entities: Summary of supplemental indicators of irrigation and delivery systems performance and crop productivity organized by spatial scale

Indicators		Spatial scales			
		Statewide(1)	Supplier	County(1)	Field
Irrigation and Delivery Systems Performance Indicators	**Distribution uniformity (DU)(2)** Indicator evaluates the performance and effectiveness of an irrigation system. **DU = Dawlq/Daw**	–	--	--	(Voluntary) on-farm irrigation evaluation
	Delivery fraction (DF)(3) Indicator evaluates the relationship between the water delivered to an area and the total applied surface or groundwater. **DF = FGD/WS**	--	Water Supplier	--	--
Crop Productivity Indicators	**Productivity of Applied Water (PAW)** Indicator illustrates the relationship between crop production in tonnage and the volume of applied water. **PAW = CY/AW**	DWR	--	DWR*	Voluntary on-farm evaluation
	Value of Applied Water (VAW) Indicator illustrates the relationship between gross crop value in dollars and the volume of applied water. **VAW = GCR/AW**	DWR	--	DWR*	Voluntary on-farm evaluation

*- would require additional funding for DWR, approximately $100,000 per year.

(1) Statewide and county scale calculations will be done based on data on annual time step and every five years and reported in the CA Water Plan Update. Cost of DU is included in the field scale methods.

(2) DU will be evaluated at the field scale and mean and standard deviation of the field values of DU will be calculated by the supplier for their service area.

(3) FGD: total farm gate deliveries; WS: surface and groundwater supplies delivered or diverted into the water supplier Distribution System

Acronyms: AWc- applied water at county scale, Daw: the average depth of applied water across the field; Dawlq: the average lower quarter depth of applied water; DF: delivery fraction; GCR: gross crop revenue; PAW: productivity of applied water; VAW; value of applied water; CY: weight of crop production.

Two of the indicators help describe the performance of the growers' irrigation system (how evenly water is applied and infiltrates into the soil) and the water supplier's delivery system (relationship of water diverted by the supplier to water delivered to its customers). The other two indicators help describe crop productivity (relationship of the volume of water applied to an area to the total crop yield and gross crop revenue).

5.1 Irrigation and Delivery System Performance Indicators

Two indicators provide information on the performance of the irrigation system, distribution uniformity (DU) and the delivery system, delivery fraction (DF).

Distribution Uniformity (DU). This is a measure of irrigation system performance—how evenly water is applied and infiltrates into the soil across a field during an irrigation event. A well-designed irrigation system applies water to crops as uniformly as possible to optimize crop production. DU is not a measure of how efficiently water is used on the field. An irrigation event can have high DU but low efficiency due to excessive tailwater or deep percolation. DU is expressed as a percentage between 0 and 100 and is typically derived from "catch can" or measurement of depth of wetted soil. It is applicable at the field scale; however, the mean and standard deviation of field scale DU values can be used to indicate irrigation performance at the water supplier scale or basin scale. DU may already be determined as described in CWC §10608.48 by suppliers greater than 25,000 acres if supplier provides on-farm irrigation evaluation.

DU is a measure of irrigation system performance in evenly distributing water to a field. An irrigation event can have high distribution uniformity (DU) but low efficiency due to excessive tailwater or deep percolation.

DU is calculated with the equation

Equation 5

DU=Dawlq/Daw

where;

- **Dawlq** is lower the quarter values of depth or applied water or infiltrated water and

- **Daw** is average depth of applied water to the field or infiltrated into soil.

Delivery Fraction (DF). This fraction evaluates the efficiency of the water supplier's water delivery system for delivering water to its customers. It is also known as conveyance efficiency. It allows the evaluation of the relationship between the water delivered to agriculture fields in a supplier service area and the total water brought into the boundary of the water supplier distribution system (plus distribution system return flows minus water used for non-agricultural crop uses). It is recommended for the water supplier scale only. Since water suppliers are reporting farm-gate deliveries and also are required to quantify their water supplies (see Table 4-1), calculation of DF is assumed to be done by suppliers.

DF is calculated with the equation

Equation 6
DF= [FGD]/[WS]

where;

- **Farm-gate delivery (FGD)** is the aggregated farm-gate delivery by the water supplier to its customers - total deliveries to individual customers. If water supplier returns the farm tailwater to its system, the return flows are measured as part of FGD.

A water supplier can evaluate its distribution system improvements by calculating DF using its total farm-gate deliveries and its water supply. Under CWC §531.10, many water suppliers are required to determine the components used to calculate DF.

- **Water supply (WS)** is the volume of surface water and groundwater, whether public or private, that enters the supplier's distribution system for delivery by the water supplier, including the distribution system return flows to its customers, and excluding water deliveries into the distribution system for non-agricultural crops and non-environmental uses (M&I) and stored for future year use. WS is calculated from diversion records and the quantity of supplier and privately pumped surface water or groundwater (measured or estimated from groundwater modeling) into the supplier's distribution system, less the amount of water entered into portions of the distribution system serving non-agricultural uses.

- The water supplier's distribution system consists of transmission systems that convey water to local storage reservoirs and the distribution systems that supply water to agricultural customers and urban customers. Water distribution systems are generally comprised of large networks of canals and pipes with branched and loop topologies with flow paths to many delivery points. In some systems, some customers receive water for M&I uses directly from transmission canals and pipes; therefore, the water supplier may exclude from its agricultural delivery system the sections of the transmission canals and pipes delivering water to the retail M&I customers. Distribution system boundaries should be defined by points of metering or measurement of the water supply. Typical measurement locations for distribution include diversion from streams and discharge points from storage reservoirs, wells feeding directly into the distribution system, recycled water, and imported water entering directly into the distribution system. Actual distribution systems may vary greatly in configuration. Therefore, each water supplier must define and delineate its distribution system for purposes of calculating Water Supply and Total Water Supply.

- **Total water supply (TWS)** is the total volume of surface water and groundwater, whether public or private, that enters the field, supplier, or basin boundary. Note that TWS includes all water supplies within a boundary whereas WS only includes water supplies that enter supplier's distribution system for delivery to agricultural customers.

5.2 Crop Productivity Indicators

Indicators have been used to show broad comparisons between regions but these indicators should not be used to conclude which crop or region uses water in a more economically efficient way.

During ASC and subcommittee meetings, two indicators relating crop productivity to applied water were identified and discussed. DWR has reported statewide trends for these indicators in the 2009 update of the California Water Plan. The two crop productivity indicators (discussed below) provide information about the relationship and trends of crop yield and/or monetary value to the volume of irrigation water applied during production. They can indicate long-term changes or trends in agricultural production and income relative to irrigation at larger spatial scales. Crop production depends on many factors other than the water to meet crop consumptive and non-consumptive needs (applied water), including water quality, climate, soil type, soil depth, crop parameters (variety), crop management (fertilizer and pest management, etc.), and water management (irrigation system, irrigation management, and water supply flexibility and reliability). However, these indicators do not quantify the efficiency of agricultural water use nor economic efficiency (see Box 5-1 Economic Efficiency). The crop productivity metrics have been used in the literature for water use efficiency in agriculture.

DWR cautions that the crop productivity indicators described in this section not be used to draw conclusions about basin crop selection because many factors other than applied water can affect crop selection, crop production, and income in any given year and location and with changing crop markets. The purpose and applicatio of these crop productivity indicators are described in this section and summarized in Table 5-1.

Box 5-1 Economic Efficiency

Economic efficiency of water use in agricultural production has several important differences from traditional physical measures of efficiency. Economic efficiency is not a single measure, but rather is a set of conditions relating input use and output[1]. Most of these conditions derive from assumptions of profit maximization, constrained profit maximization, or cost minimization. All conditions must be met for production to be called economically efficient. Economic efficiency is not an index measured on a scale such as 0 to 100 percent. Economic indicators could be, and occasionally have been developed to show broad comparisons between regions or crops or over time for a given region or crop. These indicators should not be used to draw firm conclusions about which crops or regions are using water in more economically efficient ways.

Economic efficiency conditions rely on marginal responses and rates of trade-off. Generally, these are not directly observable using aggregate data or even producer-level or field-level data. Rather, they must be estimated using statistical procedures or simulated using a model of agricultural production. For example, statistical methods can be used to infer marginal values and rates of trade-off among inputs and outputs. Results of such analysis could indicate whether a particular agricultural water use appears to meet conditions of economic efficiency from a local or broader perspective. Also, the economic effects of *changes* in water use, such as from distribution system improvements, can be quantified using standard approaches like benefit-cost analysis or cost-effectiveness analysis.

Economic efficiency is not a single, quantifiable value that is measurable on an absolute or relative scale. There are economic indicators that relate to economic efficiency and that combined with other benefits provided by agriculture could be used to help guide public policy and public investment, but with an understanding of their limitations. Importantly, crop productivity indicators described in this section do not quantify the economic efficiency of agricultural water use.

[1]A detailed description of these conditions is beyond the scope of this paper, but can be found in any advanced microeconomics textbook. Briefly, the conditions show the relationships between rates of change and substitution between inputs and outputs that would hold if commodities are being produced in an economically efficient manner.

Two indicators provide information on crop productivity—Productivity of Applied Water (PAW) and Value of Applied Water (VAW).

Productivity of Applied Water (PAW). This indicator illustrates the relationship (ratio) between crop production in tonnage and the volume of applied water. It is most applicable at the statewide and county scales.

The detailed analysis unit (DAU) is the smallest planning and analysis boundary for the California Water Plan. A number of DAUs form a planning area, which is the next larger analysis boundary. A number of planning areas in turn form a hydrologic region, and there are 10 hydrologic regions covering the entire state. See Appendix B for maps of California's county boundaries and 10 hydrologic regions and the DAUs and county boundaries within the Colorado River Hydrologic Region as an example. For example, when water suppliers' data (i.e., applied water) is used for planning purposes in DAUs, data may have to be interpolated due to mismatch in boundaries of DAUs and water suppliers

PAW is calculated with the equation

Equation 7

PAW= Crop Yield/AW

where;

- **Crop yield** (CY) would include the total production by weight or other recognized measure of yield for a crop
- **AW** is the total applied water used for agricultural crop production within the area.

This indicator must be calculated separately for each crop to avoid adding together disparate physical units of different crops. As a result, the total applied water also needs to be quantified separately by crop. Some, but not all, suppliers maintain records of crop-specific deliveries to fields. Few irrigated areas in California maintain any standard record of groundwater use on a crop-specific basis. Therefore, in most cases, estimates would have to rely on growers' field records. Suppliers' delivery records could be used if they could be matched to a particular crop and if the supplier or analyst were confident that no private pumping or other water sources were used to irrigate the crop. In the absence of these detailed data, county level production from agriculture commissioner's report and applied water calculated at county and statewide scales by DWR for the CWP update may be used to compute this productivity indicator. Calculation of applied water at the county level requires interpolation from detailed analysis units (DAUs), see Appendix B, or other appropriate scales.

Value of Applied Water (VAW). This indicator illustrates the relationship (ratio) between gross crop revenue (value) in dollars and the volume of applied water. It is most applicable at the statewide and county scales.

The ratios described here are indicators that relate to, but are not the same as, the economic efficiency of agricultural water use.

VAW is calculated with the equation

Equation 8

VAW= Gross Crop Revenue/AW

where;

- **Gross crop revenue** (GCR) includes the total gross crop value or revenue of irrigated agricultural (price multiplied by yield). The inflation-adjusted dollars of gross agricultural revenue per acre-foot of applied water is used to determine production value.
- **AW** is the total applied water surface water and groundwater pumping for irrigated agriculture within a county or statewide as computed by DWR for the CWP update. An analysis presented in Volume 4 of California Water Plan Update 2009 used this indicator to illustrate the increasing economic productivity of California agricultural water use at a statewide scale.

The VAW can increase by reducing applied water or higher crop yield/unit of water and higher prices for the crop. Because agricultural crop production is done through field survey of crops and reported by the county agricultural commissioner, DWR recommends reporting crop productivity and value of production for statewide and county scales. Application of the PAW and VAW at the field scale is difficult and limited by the lack of needed data and mechanisms of obtaining the data needed to calculate these fractions. In addition, field scale data are considered proprietary. Applied water at the field scale may be available from supplier records as long as the groundwater used is also measured by the supplier or is available from the grower. But the crop production and value of crop is only available from the growers. Therefore, the field scale PAW and VAW indicators are included in the report for consistent use by growers and are considered voluntary for field scale.

Crop productivity indicator:

VAW – Value of Applied Water

VAW = Crop Value/AW

An analysis presented in Volume 4 of California Water Plan Update 2009 used this indicator to illustrate the increasing economic productivity of California agricultural water use at a statewide scale.

Table 5-2 shows what components of indicators are calculated and which ones are empirical.

Table 5-2 Empirical and modeled components of indicators

Indicator	Equation	Empirical (observed)	Modeled
PAW-statewide	Crop yield/AW		Crop yield, AW
VAW-statewide	Gross crop revenue /AW		Gross crop revenue, AW
PAW- county	Crop yield/AW		Crop yield, AW
VAW-county	Gross crop revenue /AW		Gross crop revenue
DF-supplier	FGD/WS	FGD, WS	
DU-field	Dawlq/Daw	Dawlq, Daw	
PAW-field	Crop yield/AW	Crop yield, AW	
VAW-field	Gross crop revenue /AW	Gross crop revenue, AW	

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Appendix A. Selected Sections of California Water Code

Sections of the CWC enacted by the SB X7-7:

§10608. The Legislature finds and declares all of the following:

(a) Water is a public resource that the California Constitution protects against waste and unreasonable use.

(b) Growing population, climate change, and the need to protect and grow California's economy while protecting and restoring our fish and wildlife habitats make it essential that the state manage its water resources as efficiently as possible.

(c) Diverse regional water supply portfolios will increase water supply reliability and reduce dependence on the Delta.

(d) Reduced water use through conservation provides significant energy and environmental benefits, and can help protect water quality, improve streamflows, and reduce greenhouse gas emissions.

(e) The success of state and local water conservation programs to increase efficiency of water use is best determined on the basis of measurable outcomes related to water use or efficiency.

(f) Improvements in technology and management practices offer the potential for increasing water efficiency in California over time, providing an essential water management tool to meet the need for water for urban, agricultural, and environmental uses.

§10608.4. It is the intent of the Legislature, by the enactment of this part, to do all of the following:

(a) Require all water suppliers to increase the efficiency of use of this essential resource.

(e) Establish consistent water use efficiency planning and implementation standards for urban water suppliers and agricultural water suppliers.

(i) Require implementation of specified efficient water management practices for agricultural water suppliers.

(j) Support the economic productivity of California's agricultural, commercial, and industrial sectors.

(k) Advance regional water resources management.

§10608.8

(c) This part does not require a reduction in the total water used in the agricultural or urban sectors, because other factors, including, but not limited to, changes in agricultural economics or population growth may have greater effects on water use. This part does not limit the economic productivity of California's agricultural, commercial, or industrial sectors.

§10608.12

(a) "Agricultural water supplier" means a water supplier, either publicly or privately owned, providing water to 10,000 or more irrigated acres, excluding recycled water. "Agricultural water supplier" includes a supplier or contractor for water, regardless of the basis of right, that distributes or sells water for ultimate resale to customers. "Agricultural water supplier" does not include DWR.

§10608.64. The department, in consultation with the Agricultural Water Management Council, academic experts, and other stakeholders, shall develop a methodology for quantifying the efficiency of agricultural water use. Alternatives to be assessed shall include, but not be limited to, determination of efficiency levels based on crop type or irrigation system distribution uniformity. On or before December 31, 2011, the department shall report to the Legislature on a proposed methodology and a plan for implementation. The plan shall include the estimated implementation costs and the types of data needed to support the methodology. Nothing in this section authorizes the department to implement a methodology established pursuant to this section.

§10800

(e) There is a great amount of reuse of delivered water, both inside and outside the water service areas.

(f) Significant noncrop beneficial uses are associated with agricultural water use, including streamflows and wildlife habitat.

(h) Changes in water management practices should be carefully planned and implemented to minimize adverse effects on other beneficial uses currently being served.

Sections of the California Water Code enacted by AB 1404

§531.10

(a) An agricultural water supplier shall submit an annual report to the department that summarizes aggregated farm-gate delivery data, on a monthly or bimonthly basis, using best professional practices.

(b) Nothing in this article shall be construed to require the implementation of water measurement programs or practices that are not locally cost effective.

§531. Unless the context otherwise requires, the definitions set forth in this section govern the construction of this article.

(a) "Aggregated farm-gate delivery data" means information reflecting the total volume of water an agricultural water supplier provides to its customers and is calculated by totaling its deliveries to individual customers.

(b) "Agricultural water supplier" means a supplier either publicly or privately owned, supplying 2,000 acre-feet or more of surface water annually for agricultural purposes or serving 2,000 or more acres of agricultural land. An agricultural water supplier includes a supplier or contractor

for water, regardless of the basis of right, which distributes or sells water for ultimate resale to customers.

Agricultural water management planning and implementation enacted by SB X7-7

§10820

(a) An agricultural water supplier shall prepare and adopt an agricultural water management plan in the manner set forth in this chapter on or before December 31, 2012, and shall update that plan on December 31, 2015, and on or before December 31 every five years thereafter.

(b) Every supplier that becomes an agricultural water supplier after December 31, 2012, shall prepare and adopt an agricultural water management plan within one year after the date it has become an agricultural water supplier.

§10826. An agricultural water management plan shall be adopted in accordance with this chapter. The plan shall do all of the following:

(a) Describe the agricultural water supplier and the service area, including all of the following:

(1) Size of the service area.

(2) Location of the service area and its water management facilities.

(3) Terrain and soils.

(4) Climate.

(5) Operating rules and regulations.

(6) Water delivery measurements or calculations.

(7) Water rate schedules and billing.

(8) Water shortage allocation policies.

(b) Describe the quantity and quality of water resources of the agricultural water supplier, including all of the following:

(1) Surface water supply.

(2) Groundwater supply.

(3) Other water supplies.

(4) Source water quality monitoring practices.

(5) Water uses within the agricultural water supplier's service area, including all of the following:

(A) Agricultural.

(B) Environmental.

(C) Recreational.

(D) Municipal and industrial.

(E) Groundwater recharge.

(F) Transfers and exchanges.

(G) Other water uses.

(6) Drainage from the water supplier's service area.

(7) Water accounting, including all of the following:

(A) Quantifying the water supplier's water supplies.

(B) Tabulating water uses.

(C) Overall water budget.

(8) Water supply reliability.

(c) Include an analysis, based on available information, of the effect of climate change on future water supplies.

(d) Describe previous water management activities.

(e) Include in the plan the water use efficiency information required pursuant to Section 10608.48.

§10608.48. (a) On or before July 31, 2012, an agricultural water supplier shall implement efficient water management practices pursuant to subdivisions (b) and (c).

(b) Agricultural water suppliers shall implement all of the following critical efficient management practices:

(1) Measure the volume of water delivered to customers with sufficient accuracy to comply with subdivision (a) of Section 531.10 and to implement paragraph (2).

(2) Adopt a pricing structure for water customers based at least in part on quantity delivered.

(c) Agricultural water suppliers shall implement additional efficient management practices, including, but not limited to, practices to accomplish all of the following, if the measures are locally cost effective and technically feasible:

(1) Facilitate alternative land use for lands with exceptionally high water duties or whose irrigation contributes to significant problems, including drainage.

(2) Facilitate use of available recycled water that otherwise would not be used beneficially, meets all health and safety criteria, and does not harm crops or soils.

(3) Facilitate the financing of capital improvements for on-farm irrigation systems.

(4) Implement an incentive pricing structure that promotes one or more of the following goals:

(A) More efficient water use at the farm level.

(B) Conjunctive use of groundwater.

(C) Appropriate increase of groundwater recharge.

(D) Reduction in problem drainage.

(E) Improved management of environmental resources.

(F) Effective management of all water sources throughout the year by adjusting seasonal pricing structures based on current conditions.

(5) Expand line or pipe distribution systems, and construct regulatory reservoirs to increase distribution system flexibility and capacity, decrease maintenance, and reduce seepage.

(6) Increase flexibility in water ordering by, and delivery to, water customers within operational limits.

(7) Construct and operate supplier spill and tailwater recovery systems.

(8) Increase planned conjunctive use of surface water and groundwater within the supplier service area.

(9) Automate canal control structures.

(10) Facilitate or promote customer pump testing and evaluation.

(11) Designate a water conservation coordinator who will develop and implement the water management plan and prepare progress reports.

(12) Provide for the availability of water management services to water users. These services may include, but are not limited to, all of the following:

(A) On-farm irrigation and drainage system evaluations.

(B) Normal year and real-time irrigation scheduling and crop evapotranspiration information.

(C) Surface water, groundwater, and drainage water quantity and quality data.

(D) Agricultural water management educational programs and materials for farmers, staff, and the public.

(13) Evaluate the policies of agencies that provide the supplier with water to identify the potential for institutional changes to allow more flexible water deliveries and storage.

(14) Evaluate and improve the efficiencies of the supplier's pumps.

(d) Agricultural water suppliers shall include in the agricultural water management plans required pursuant to Part 2.8 (commencing with Section 10800) a report on which efficient water management practices have been implemented and are planned to be implemented, an estimate of the water use efficiency improvements that have occurred since the last report, and an estimate of the water use efficiency improvements estimated to occur five and 10 years in the future. If an agricultural water supplier determines that an efficient water management practice is not locally cost effective or technically feasible

§10608.48

(d) Agricultural water suppliers shall include in the agricultural water management plans required pursuant to Part 2.8 (commencing with Section 10800) a report on which efficient water management practices have been implemented and are planned to be implemented, an estimate of the water use efficiency improvements that have occurred since the last report, and an estimate of the water use efficiency improvements estimated to occur five and 10 years in the future. If an agricultural water supplier determines that an efficient water management practice is not locally cost effective or technically feasible, the supplier shall submit information documenting that determination.

(e) The data shall be reported using a standardized form developed pursuant to Section 10608.52.

(f) An agricultural water supplier may meet the requirements of subdivisions (d) and (e) by submitting to the department a water conservation plan submitted to the United States Bureau of Reclamation that meets the requirements described in Section 10828.

(h) The department may update the efficient water management practices required pursuant to subdivision (c), in consultation with the Agricultural Water Management Council, the United States Bureau of Reclamation, and the board. All efficient water management practices for agricultural water use pursuant to this chapter shall be adopted or revised by the department only after the department conducts public hearings to allow participation of the diverse geographical areas and interests of the state.

Appendix B. Maps

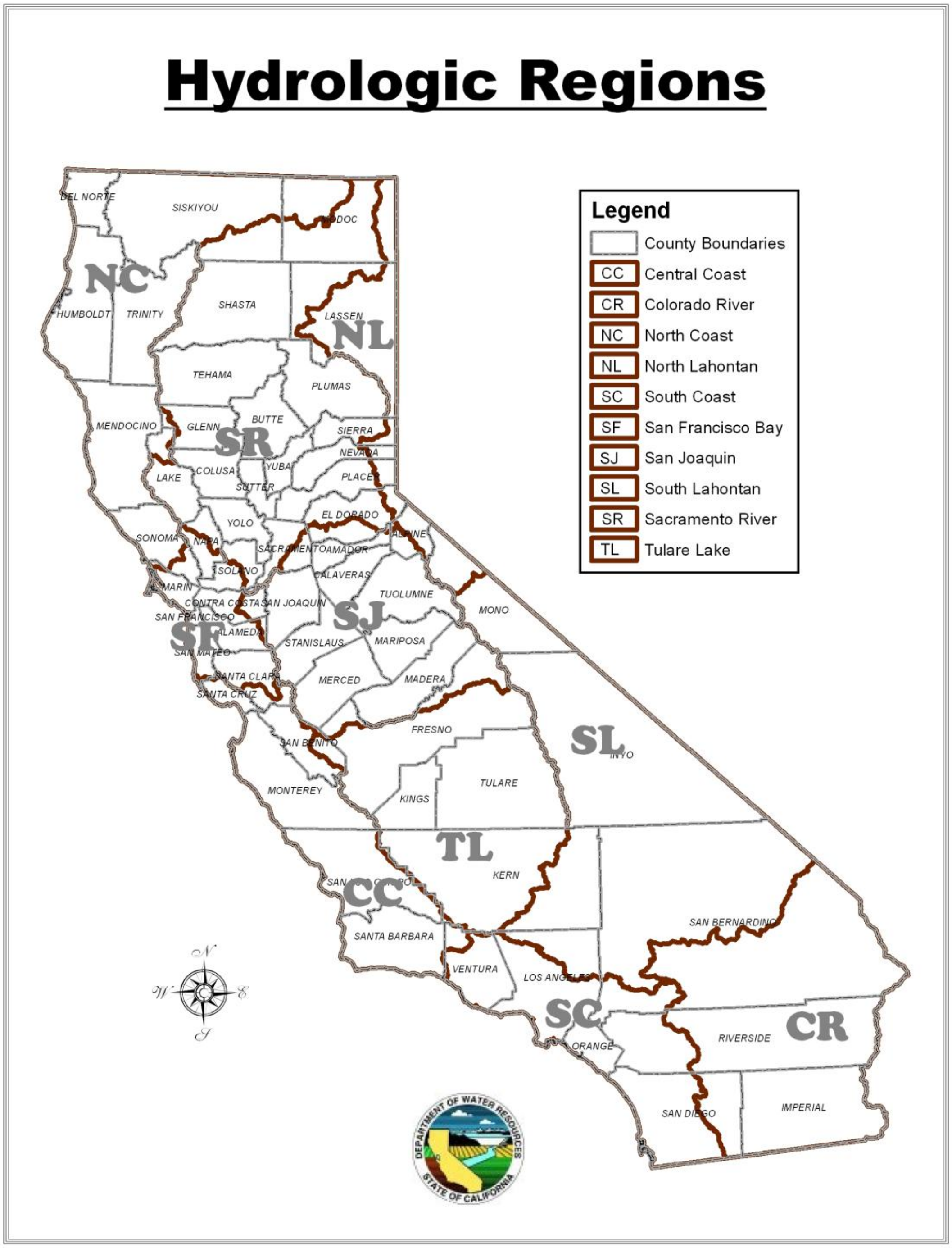

Figure B-1 DWR hydrologic regions including county boundaries

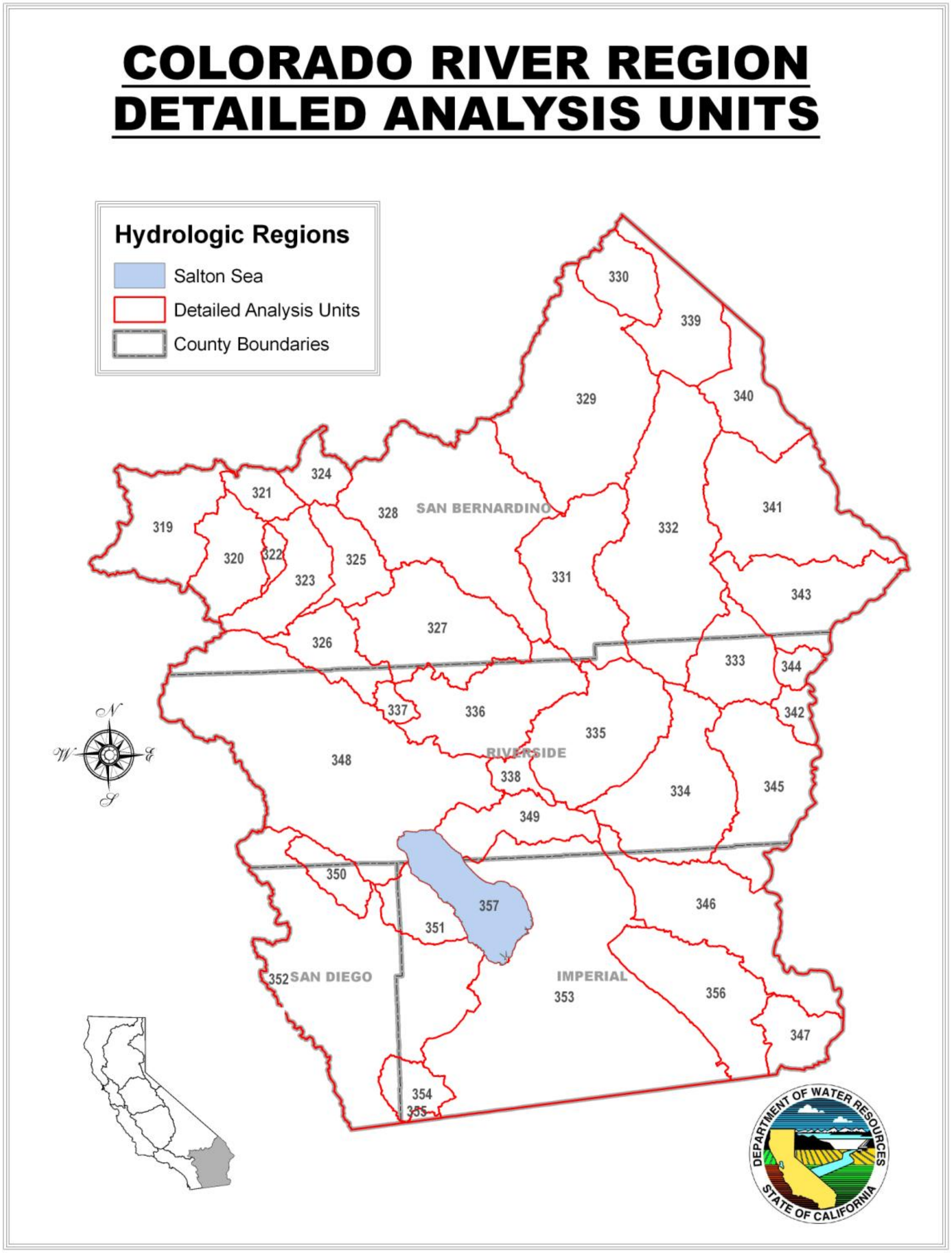

Figure B-2 DWR detailed analysis units for the Colorado River Hydrologic Region and respective counties

Appendix C. Calculation Examples of Water Use Efficiency Quantification Methods and Indicators

C.1 Calculation Examples of Quantifying the Efficiency of Agricultural Water Use and Irrigation System Performance Indicators

None of the assumed quantities or percentages used in the examples necessarily represents acceptable default value.

C.1.1 Water Supplier Scale Calculation Example 1

Water supplier is 45,000 acres and additional details are in Table C-1 and in this example, each method is calculated at the supplier scale in Table C-1.

Table C-1 Water supplier scale water use efficiency quantification methods and Indicators, example 1

(see also Table C-3 for additional applicable details)

Quantifying the Efficiency of Agricultural Water Use and irrigation System Performance

Elements	Explanations	Calculations
ETAW	Evapotranspiration of applied water (ETAW) can be calculated as the seasonal total crop evapotranspiration (ET) minus the cumulative effective rainfall contribution (Pe), estimated assuming that 20 percent of total precipitation from January to the end of irrigation season contributes to ETc. Therefore, the total ETAW can be expressed as ETAW = (ET – Pe) X crop acreage. In-season weighted mean crop coefficient curves (Kc) for a crop is used with the cumulative reference evapotranspiration (ETo) to determine total seasonal crop evapotranspiration, ET. A sample calculation of a seasonal crop water balance for a tomato crop grown at Davis, California is shown below. A weighted mean Kc value of 0.82 for the periods of planting to harvest was used to represent tomato. For simplification, the values of Kc for the different periods within the growing season are represented as straight lines. The cumulative ETo value obtained from the CIMIS station at Davis for the cropping season is 2.92 ft. ET = ETo X Weighted mean Kc = 2.92 X 0.82 = 2.40 ft Pe = Total Precipitation X 20% = 1.15 X 20% = 0.23 ft Crop acreage = 45,000 acre Substituting these values in the proposed equation yields ETAW= (ET-Pe)= (2.4-.23)=2.2 ft ETAW = (2.2) X 45,000 = 99,000 AF per year Note- ETAW calculated above was compared with predictions of ETAW with the CUP plus application program "Consumptive Use Program Plus" or "daily soil water balance program" developed to estimate daily soil water balance to determine ETc and ETAW for agricultural crops and other surfaces that account for ET losses and water contributions of rainfall and irrigation water (see Appendix D). The calculations require input of weather or climate data, soil depth and water-holding capacity, crop root depth, and seasonal crop coefficient curves. Estimates of ETAW compared well with CUP plus; for example, the total ET estimates for tomato at Davis for 2010 were 2.40 ft and 2.5 of ET and Pe of 0.23 ft and 0.16 ft for this method and CUP plus respectively, a difference in ETAW value of roughly 6%.	ETAW= 2.2x45,000= 99,000 AF per year
Agronomic	Seasonal evapotranspiration of a tomato crop (ET) grown in Yolo County in 2010 is 2.4 ft. Electrical conductivity (ECi) of irrigation water is 1.0 ds/m. LR is calculated as: $$\mathrm{LR} = \frac{\mathrm{EC_i}}{5(\mathrm{EC_e}) - \mathrm{EC_i}}$$ The ECe from Table D-1 for tomato at a 100 percent yield potential is 2.5 ds/m, therefore: $$\mathrm{LR} = \frac{1.1}{5(2.5) - 1.1} = 0.10$$ Agronomic Use (AU) can be estimates as: AU = (LR X ETAW X crop acreage) Substituting these values in the above equation yields The AU is the amount of applied irrigation water needed to meet leaching requirement of a tomato crop grown in Yolo County in 2010. Seed bed preparation is 6120 af, 3600 af of it is towards ETAW. Net AU= 9,900+ 2520=12,420af	AU = (0.10 X 2.2 X 45,000) = 9,900 AF per year plus 2520 af=12,420 af

Elements	Explanations	Calculations
Environmental	Garter snake habitat maintained on canal banks; plants assumed to have ET = 4 AF/A (Sudan grass). Approximately 50 acres of habitat. Water use =ETxArea	Canal habitat: EU= 4x50= 200 AF per year
	Several fields are flooded in fall/winter to provide habitat for migratory birds. Approx 6-inches per acre of net water for 8,000 acres in supplier's boundary are used. Water use= ETxArea	Field habitat = (6/12)x 8,000=4,000 AF per year
	Supplier is required to maintain 6 cubic feet per second (cfs) flows in drain from June 1 through October 30 for habitat. Water use= (flow)x(Duration)= (6 cfs)(3600x24 sec/day)/(43,560 af/cf)(150 day)=1,800 AF	Drain flows = 1,800 AF per year Total EU= 200+4,000+ 1,800= 6,000 af per year
Aggregate Farm-gate Deliveries	Estimate provided by water supplier in monthly measured billings.	Aggregate farm-gate deliveries per year = 148,555 af/year
Recoverable Flows	This value is estimated using several sources of data and calculations:	-
	Using data from gauge on the drain (above).	Drain data = 1,800 AF per year
	It is estimated that 2 inches per acre of leaching requirements are deep percolation.	Estimated deep percolation from leaching = (2/12)(45,000)= 7,500 AF per year
	The remaining portion of the total delivered water that is not crop ET, agronomic water and environmental water is identified. =AW-ETAW-EU-AU	Estimated additional deep percolation (not from leaching) =160,920-99,000-12,420-6,000=43,500 af
	Based on the estimate of the acreage of non-cropped area, 20% is used by non-crop plants that are not part of intentional environmental objectives therefore, irrecoverable.	20%(43,500)= 8,700 af
	The portion remaining is considered returning as additional deep percolation to that from intentional leaching	80% (43,500) =34,800 AF per year Total estimated recoverable flows = 1,800 + 7,500 + 34,800 = 44,100 AF/yr
Supplier Scale Water Supply and Applied Water	Water supplier has river diversion only. Quantity diverted by the supplier is derived from records for filing to the SWRCB. The supplier and privately pumped groundwater is estimated from power usage records.	Supplier diversions = 156,420 AF/yr Estimated GW pumped = 19,500 AF/yr. Total WS =175,920 AF
	Total deliveries to non-irrigation agriculture and M&I are subtracted from the total water supplies. Delivered water also excludes groundwater recharge and accounts for the net change in surface storage within the water supplier's boundaries. Initial soil moisture in soil profile is accounted for, 1000 af.	Supplier non-irrigation agricultural deliveries = 10,000 AF/yr Supplier M&I deliveries = 4,000 AF/yr Soil moisture 1,000 AF. Applied water per year = 175,920-10,000-4,000-1,000= 160,920 AF per year

Results

CCUF=ETAW/[AW]	= {99,000/(160,920)} x 100= 61%	61% of applied water is used for crop consumption. 39% of the applied water is used for environmental use , agronomic use and recoverable and irrecoverable flows
AWUF=[ETAW+AU]/AW	={99,000+12,420}/(160,920)}x100=69%	69% is used for crop needs.
TWUF= [ETAW+AU+EU]/AW	={(99,000+12,420+6,000)/160,920} x 100=73%	73% Percentage of applied water is used for crop needs and environmental use, the remaining 27% is recoverable and irrecoverable flows.
DF=FGD/WS	={ (148,555)/160,920} x 100=92%	92% of the water supply in the distribution system is delivered to the water supplier customers and 8% is not delivered to customers and lost to recoverable (to other suppliers) or to salt sink irrecoverable flows.
WMF=[ETAW+RF]/AW	= {(99,000+44,100)/160,920} x 100=89%	Comparison of WMF (89%) with CCUF (61%) indicates that 28% of flow is recoverable within the boundary.

C.1.2 Water Supplier Scale Calculation Example 2

The following example is similar to supplier example 1 but with irrecoverable flow. Using this example, each method is calculated at the water supplier scale in Table C-2.

Table C-2 Water supplier scale water use efficiency quantification methods and Indicators, example 2

Quantifying the Efficiency of Agricultural Water Use and Irrigation System Performance Indicators

Elements	Explanations	Calculations
ETAW	Same as Example 1	Example Option 1 = 99,000 AF per year
Agronomic	Same as Example 1	Approx = 12,420 AF per year
Environmental	Same as Example 1	Canal habitat = 200 AF per year Field habitat = 4,000 AF per year Drain flows = 1,800 AF per year Total EN= 6,000 af per year
Aggregate farm-gate delivery	Same as Example 1	Aggregate Field Scale AW per year = 148,555
Recoverable Flows	This value is estimated using data from gauge on the drain	Drain data = 1,800 AF per year
Irrecoverable flows	Supplier measures its drainage discharge to evaporation ponds	Drainage to ponds 42,300 af/year
Supplier Scale Water Supply and Applied Water	Same as Example 1	Supplier diversions = 156,420 AF per year Estimated GW pumped = 19,500 AF per year Supplier non-irrigation agricultural deliveries = 10,000 AF per year Supplier M&I deliveries = 4,000 AF per year soil moisture 1000 AF. Applied water per year = 160,920 AF per year
Results		
CCUF=ETAW/AW	= {99,000/(160,920)} x 100	= 61%
AWUF=[ETAW+AU]/AW	= {(99,000+12,420)/(160,920)} x 100	= 69%
TWUF=[ETAW+AU+EU]/AW	={(99,000+12,420+6,000)/160,920} x 100	=73%
DF=FGD/WS	={ (148,555)/160,920} x 100	= 92%
WMF=[ETAW+RF]/AW	= {(99,000+1800)/160,920} x 100	= 63%. This supplier has smaller WMF than supplier 1 because some of its water (42,300 af) is irrecoverable.

C.1.3 Field Scale

To provide insight into the use of the methods at the field scale, the following example was developed. Under this example, the field consists of 125 acres of processing tomatoes; planted from seed in raised beds and furrow irrigated. The field scale deliveries are augmented with groundwater pumping and the net change in surface storage and soil moisture are accounted for. Using this example for a single growing season, each method is calculated at the field scale in Table C-3.

Table C-3 Field scale example of water use efficiency quantification methods and irrigation system performance Indicator

Quantifying the Efficiency of Agricultural Water Use and Irrigation System Performance Indicator

Elements	Explanations	Calculations
ETAW	Similar to Example 1. See Table C-1 for details. ETo= 2.92 ft Kc=0.82 Pe=0.23 ft ET=ETोxKc Area= 125 acres ETAW= (ET-Pe)xArea	ET=2.92x0.82=2.4 ETAW=(2.4-0.23)x 125= 275 AF
Agronomic Use	Similar to example 1 assumptions. LR= 0.1 Area= 125 Acres ETAW= 2.2 AU= ((LR)(ETAW)(Area)=	LR = (0.1)(2.2)(125)= 27.5 AF per season Seed bed preparation= 17 AF per season Total = 44.5 AF per season (of this amount, 10 AF of the seed bed water doubles as water for ETAW, which results in a net agronomic quantity of 34.5 AF). Net agronomic use =34.5 af/year
Environmental Use	Small wetland and garter snake habitat maintained on field edges; plants assumed to use water like a grass hay such as Sudan, 4 AF/Y; approximately 5 acres of habitat	Habitat = 20 AF per year
Distributional Uniformity	Average low quarter applied water depth of a field relative to the average depth of water applied to the entire field for one irrigation event.	Average low quarter depth = 2.8 inches per irrigation event Average applied water depth = 3.8 inches per irrigation event
Field Scale Applied Water	Estimate provided by water supplier in monthly measured deliveries delivery is applied to the field. Field level groundwater pumping (10 af) and net change in surface storage and/or soil moisture (3 af).	413 AF AW per season [surface diversion is 400 af per season, 10 AF per season of private groundwater pumping 3 AF soil moisture in the field from previous season. For a total of 413 AF of AWf]
Results		
DU= Dawlq/Daw	={2.8/3.8} x 100= 74%	DU is an Indicator of water use efficiency but is reported here because it is generally done by on-farm irrigation evaluation.
CCUF= ETAW/(AW)	= {275/(413)} x 100=67%	Percentage of applied water used by field crops. 33% of applied water is non beneficial evapotranspiration, recoverable or irrecoverable deep percolation, and tailwater.
AWUF=(ETAW+AU)/AW	= {(275+34.5)/(413)} x 100=75%	75% used and 25% are recoverable and irrecoverable.
TWUF =(ETAW+AU+EU)/AW	= {(275+34.5+20)/413} x 100=80%	80% Percentage of applied water is used, 20% is recoverable or irrecoverable flows (non beneficial evapotranspiration, recoverable or irrecoverable deep percolation, and tailwater).

C.2 Calculation Examples of Productivity Indicators

The purpose of the indicators are:

- Evaluate crop production (in weight or gross crop revenue) per acre-foot of applied water within a defined scale.
- Evaluate how production (in weight or gross crop revenue) per acre-feet changed over time within a defined scale.

Table C-4 presents the gross crop revenue or gross value per acre-foot of applied water (VAW) for each of the significant crops or crop groups in Fresno County in California expressed in terms of 2010 dollars per acre-foot of applied water.

Table C-4 Example of the productivity indicator calculated for Fresno County scale

Summary table Fresno County crop group or crop	2010 irrigated harvested acres	Gross crop revenue from irrig. acres ($1,000s)	Total applied water (1,000s AF)	Avg. gross crop revenue per AF of applied water
Field crops	371,885	361,861	989.3	366
Seed crops	24,030	50,957	79.1	644
Truck crops	258,220	1,528,285	448.0	3,411
Tree & vine crops	471,037	2,702,906	1,366.1	1,979
Nursery products	715	37,478	1.6	23,424
All crops	1,125,887	4,681,487	2,884.2	1,623
Selected crop				
Corn silage	40,700	38,332	105.8	362
Cotton, pima	57,000	126,068	148.2	851
Hay, alfalfa	68,100	75,210	279.2	269
Hay, other	26,435	10,322	44.9	230
Wheat	61,408	41,149	55.3	744
Irrigated pasture	40,000	5,000	172.0	29
Rice	2,650	2,041	13.8	148
Cantaloupes	19,100	75,429	26.7	2,825
Onions, fresh	17,300	117,500	36.3	3,237
Tomatoes, proc.	107,900	347,208	205.0	1,694
Almonds	137,930	581,230	455.2	1,277
Grapes, raisin	137,644	487,000	330.3	1,474
Grape, wine	40,209	200,945	96.5	2,082
Pistachios	26,740	222,480	88.2	2,522

All estimates exclude federal crop support payments.

The above summary table indicates that in 2010, the average gross crop revenue per acre-foot of applied water in Fresno County was $1,623/AF.

County Crop Reports

Each California County with significant agriculture has an Agricultural Commissioner's Office, which produces annual Crop Reports. These reports are also known as "Crop and Livestock Reports" or other similar titles. They are usually published from May through October of the year following the year of record for that report. They contain data for that year and the previous year. For instance, the 2010 Fresno County Crop Report was published in the summer of 2011, and contains data on 2009 and 2010 agricultural production in Fresno County.

Farm-gate prices represent the value of the farm output at the farm's gate or just before it leaves the farm for the packing shed, ginner, huller, drier, processing plant, or buyer. FOB prices represent the farm-gate value of the farm output, plus the costs to haul that output to the first off-farm receiving point, such as a packing shed or processing plant, plus varying degrees of other value-added steps, including sorting, grading, cooling, packing, hulling, ginning, and processing. Sometimes the FOB price of a crop is 2 to 3 times greater than its farm-gate price.

The Crop Reports of most County Agricultural Commissioner's Offices give the values of most field crops in terms of their farm-gate values. They give the values of truck crops (or "Vegetables and Melons") in terms of their farm gate or FOB values, or a combination of both values. The Crop Reports for most California counties give the values of most tree and vine crops (or "Fruits and Nuts") in terms of FOB values (although wine grape values are usually given at the farm gate level.)

County Crop Reports contain estimates for the two most recent years for all significant crops of harvested acres, average yield per acre, total production, average farm gate or FOB price per unit, and total gross crop revenue or total value of production. The broad crop groups are generally known as field crops, seed crops, vegetables and melons, fruit and nut crops, and nursery products. County Crop Reports also contain estimates of production and value for the various sectors of animal agriculture.

Applied Water Estimates

DWR's Land and Water Use Scientists in the Regional Offices produce estimates of applied water per acre per water year for 20 important crops or broad crop groups for each of the important agricultural counties in California for specific recent years. These unit applied water use estimates are developed for use in DWR's California Water Plan Update series, as well as for other DWR projects and publications.

The AF/acre AW estimates were for WY2005 for Fresno County, and were produced by DWR's Cal Ag Water Use Model. According to Regional Office staff, hydrologic and growing conditions in WY2005 were most similar to 2010 conditions Fresno County, when compared to such conditions in other recent water years.

Valuable data from recent DWR Land Use Surveys of Fresno County was also used, along with information and data from Land and Water Use Scientists in DWR's South Central Regional Office. Information from a January 2012 personal communications with staff of the Colusa County Agricultural Commissioner's Office was also used for these calculations.

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Appendix D. Parameter Descriptions and Calculations

Crop evapotranspiration (ETc) - is a loss of water to the atmosphere by the combined processes of evaporation from crop and soil surfaces and transpiration from crops. It is the amount of water that a well-fertilized, disease-free, crop grown in a large field under optimum soil moisture condition needs to produce a full yield. In quantifying the efficiency of agricultural water use at all spatial scales, the implementing entity can either measure ETc or estimate it using theoretical and/or empirical equations. Measurement methods use complex equipment such as Eddy Covariance, Bowen Ratio, and lysimeters, which are very intricate and therefore costly.

The most commonly used approach for estimating ETc is to use reference evapotranspiration (ETo) and crop coefficients (Kc).

$$ETc = Kc * ETo$$

ETo is evapotranspiration from standardized grass surfaces and is calculated using theoretical and empirical equations that utilize weather parameters measured on such surfaces. To relate ETo to ETc, one needs to use a crop factor commonly known as a crop coefficient. Kc is developed for various crops through research. An important source of ETo and Kc data for California is the California Irrigation Management Information System (CIMIS). CIMIS is a network of over 140 automated weather stations scattered throughout California that provide ETo and weather data to the public free of charge (http://wwwcimis.water.ca.gov/cimis/welcome.jsp). CIMIS also provides spatially distributed values of ETo at 2-km grids by coupling remotely sensed satellite data with point measurements.

Under soil water stress conditions, a water stress coefficient (Ks) is incorporated into Kc to account for water stress on crop transpiration. The term actual crop evapotranspiration (ETa) or adjusted crop evapotranspriation (ETc adj) is often used under such condition. Water stress coefficient for limiting conditions is less than 1 (Ks<1), and under no soil water stress it is equal to1 (Ks = 1).

$$\text{ETa}=\text{ETc adj}=\text{Ks} * \text{Kc} * \text{ETo}$$

However, under no water stress conditions (Ks = 1), and ETc is equal to ETa. Water stress coefficient (Ks) is usually empirically derived. Oftentimes field capacity, yield reducing threshold water content, and permanent wilting point are used to compute Ks.

In addition to the method above, for small regions or large regions, actual evapotranspiration can be estimation using satellite remote sensing.

Remote Sensing of ET. Recent developments in remote sensing have enabled researchers to estimate both ETo and ETa and derive spatially distributed values at various resolutions. In other words, remotely sensed data is used to generate ETo and/or ETa maps. Some of the remote sensing methods use the energy balance approach and calculate ET as a residual. Others use a vegetation index approach that is calibrated to the crop coefficient (Gonzalez-Dugo et al., 2009). Others couple remotely sensed parameters with numerical models or point measurements to generate ET information. It is recommended that any remote sensing method selected for implementation of agricultural water use efficiency be verified for accuracy in an environment where it is to be utilized.

For detailed analyses of actual crop evapotranspiration, one can also use the dual crop coefficient approach (FAO-56). This approach differentiates between plant transpiration and soil surface evaporation using basal crop coefficients (Kcb) and soil water evaporation (Ke). Kc is, therefore, an arithmetic sum of Kcb and Ke (i.e., Kc = Kcb + Ke). Kcb is the ratio of ETo to ETc when the soil surface is dry but the root zone can still provide plenty of water for crop growth. Ke is zero when the soil surface is dry and evaporation only takes place by capillary rise, and increases as the moisture content of the soil surface increases.

Due to the complexity of using Ks, Kcb, and Ke terms, DWR recommends the use of simple Kc values from published works to estimate ETc. Users who have the resources required to use the more complex approach can, however, use the dual crop coefficient approach. In either case, it is important for users to verify that the Kc values they are using are derived from the same ETo equation. In other words, Kc values derived using the Penman-Monteith (PM) ETo should only be used with PM ETo values to estimate ETc. Since most of the ETo values for California come from the California Irrigation Management Information System (CIMIS), DWR recommends the use of Kc values from the CIMIS web site (http://wwwcimis.water.ca.gov). Additional resources for Kc values include the UC Cooperative Extension Leaflets (for example, leaflets #21427 and #21428) and updated Kc values from local farm advisors and extension workers.

D.1 Models for Calculation Applied Water, ETAW, and Effective Precipitation

"Consumptive Use Program +" ("CUP+") is a user-friendly Microsoft Excel application that estimates daily soil water balance to estimate Etc and ETAW for agricultural crops and other surfaces that account for ET losses, such as water contributions from seepage of groundwater, rainfall, and irrigation within a study area over the period of record. The application computes Eto from daily solar radiation, maximum and minimum temperature, dew point temperature, and wind speed using the daily Penman-Monteith equation. In addition, the program uses a curve fitting technique to derive one year of daily weather data from the monthly data and estimate daily Eto. CUP+ accounts for the influence of orchard cover crops on Kc values and for immaturity effects on Kc values for tree and vine crops. The water balance model is similar to that used in the SIMETAW application program. The application outputs a wide range of tables and charts that are useful for irrigation planning.

D.2 Estimates of Effective Rainfall (Precipitation) and ETAW Using CUP+

Soil water-holding characteristics, effective rooting depths, and irrigation frequency are used with rainfall and crop evapotranspiration (ETc) data to calculate a daily soil water balance and determine effective rainfall and ETaw, which is equal to the seasonal cumulative ETc minus the effective rainfall. Irrigations are timed so that the estimated soil water depletion (SWD) does not exceed the yield threshold depletion (YTD), which is calculated as the product of the allowable depletion and the plant available water content within the crop rooting depth. The smaller soil root depth and the water holding characteristics are used to determine the plant available water (PAW). The allowable depletion is a crop and soil specific factor defining the fraction (or percentage) of the available water content within a rooting zone that can be depleted between irrigation events. For many crop and soil combinations, an allowable depletion of 50% is adequate.

Weighted crop coefficient curves are used with the daily ETo estimates to calculate daily ETc. The ETc is subtracted from the soil water content (SWC) on each day until the soil water depletion (SWD) exceeds the YTD. Then an irrigation is applied and the soil water depletion goes back to zero (i.e. back to field capacity). Similarly, rainfall will decrease the soil water depletion to zero but never into the negative. When rainfall depths are greater than the SWD, the rainfall is only effective up to a depth equal to SWD. Effective rainfall (Pe) is calculated from the estimated precipitation (Pcp) and the soil water depletion. If the precipitation (Pcp) is less than the SWD, then Pe = Pcp. Otherwise, Pe = SWD, and the daily change in soil water content is SWD = ETc – Pe = 0. There is no correction for runoff or run on to the field. It is assumed that if rainfall is sufficient to have appreciable runoff, then the soil will be filled to field capacity.

By definition, ETAW is the amount of applied irrigation water that contributes to ETc; therefore, ETAW is the sum of the net irrigation applications (NA) during a cropping season. The ETAW for no irrigation events is therefore calculated as ETAW = NA1 + NA2 + -.. + NAn.

Alternatively, ETAW can be calculated as the seasonal total evapotranspiration minus the cumulative effective rainfall contribution minus the difference in soil water content from the beginning to the end of the season (http://www.water.ca.gov/landwateruse/models.cfm).

Another source of estimating effective precipitation is a DWR publication titled "Effective Precipitation: A Study to Assess Consumptive Use of Winter Rains by Spring and Summer Crops, February 1989, DWR Central District". Its findings are summarized in the box below.

Box D-1 Estimating Effective Precipitation

Total monthly rainfall and corresponding change in soil moisture content were measured during winter at about 10 sites in the Central Valley. The 4-year study, which began in 1983, showed:

- The relationship between total rainfall and change in soil moisture is remarkably similar for each of the four winter months: November, December, January, and February. The relationship is:

  Soil moisture change = -0.54 + 0.940 (rainfall amount)

- Soil moisture content increases linearly with increased monthly rainfall for each of the four months. Surface evaporation is relatively constant, at 0.6 to 0.8 inch per month.
- In October, when the soil is initially dry, both the amount of stored soil moisture and the amount of evaporation from the soil surface increase with increasing amounts of total monthly rain. Change in stored soil moisture is linearly related to October rainfall as:

  Soil moisture change = -0.06 + 0.635 (rainfall amount)

- In March, when initial soil moisture content is generally high and evaporative demand is also high, surface evaporation rates are twice those for the four winter months, and the amount of rain going to soil moisture storage during March is correspondingly low. This is shown in the relationship:

  Soil moisture change = -1.07 + 0.837 (rainfall amount).

The relationships shown above provide a rational basis for partitioning winter rain falling on fallow land (and excluding runoff) into:

- Stored soil moisture (effective precipitation),
- Evaporation from the soil surface, and
- Percolation to below the crop rooting depth.

AG Model: The Agricultural Water Use Model was developed by the DWR's Northern Region to use monthly pan evaporation and pan coefficient data to estimate monthly Etc and ETAW for 20 crop categories by DAU/County for the Water Plan Update. Currently, the Northern and South Central Region Offices are using the Ag Model to develop their annual agricultural water use data for 20 crop categories for the CWP update 2013.

Table D-1 Crop tolerance and yield potential of selected crops as influenced by irrigation water salinity (EC_w) or soil salinity (EC_e)[1]

Yield potential[2]

	100%		90%		75%		50%		0% "maximum"[3]	
	EC_e	EC_w	EC_e	EC_w	EC_e	EC_w	EC_e	EC_w	EC_e	EC_w
Field Crops										
Barley *(Hordeum vulgare)*[4]	8.0	5.3	10	6.7	13	8.7	18	12	28	19
Cotton *(Gossypium hirsutum)*	7.7	5.1	9.6	6.4	13	8.4	17	12	27	18
Sugarbeet *(Beta vulgaris)*[5]	7.0	4.7	8.7	5.8	11	7.5	15	10	24	16
Sorghum *(Sorghum bicolor)*	6.8	4.5	7.4	5.0	8.4	5.6	9.9	6.7	13	8.7
Wheat *(Triticum aestivum)*[4,6]	6.0	4.0	7.4	4.9	9.5	6.3	13	8.7	20	13
Wheat, durum *(Triticum turgidum)*	5.7	3.8	7.6	5.0	10	6.9	15	10	24	16
Soybean *(Glycine max)*	5.0	3.3	5.5	3.7	6.3	4.2	7.5	5.0	10	6.7
Cowpea *(Vigna unguiculata)*	4.9	3.3	5.7	3.8	7.0	4.7	9.1	6.0	13	8.8
Groundnut (Peanut) *(Arachis hypogaea)*	3.2	2.1	3.5	2.4	4.1	2.7	4.9	3.3	6.6	4.4
Rice (paddy) *(Oriza sativa)*	3.0	2.0	3.8	2.6	5.1	3.4	7.2	4.8	11	7.6
Sugarcane *(Saccharum officinarum)*	1.7	1.1	3.4	2.3	5.9	4.0	10	6.8	19	12
Corn (maize) *(Zea mays)*	1.7	1.1	2.5	1.7	3.8	2.5	5.9	3.9	10	6.7
Flax *(Linum usitatissimum)*	1.7	1.1	2.5	1.7	3.8	2.5	5.9	3.9	10	6.7
Broadbean *(Vicia faba)*	1.5	1.1	2.6	1.8	4.2	2.0	6.8	4.5	12	8.0
Bean *(Phaseolus vulgaris)*	1.0	0.7	1.5	1.0	2.3	1.5	3.6	2.4	6.3	4.2
Vegetable crops										
Squash, zucchini (courgette) *(Cucurbita pepo melopepo)*	4.7	3.1	5.8	3.8	7.4	4.9	10	6.7	15	10
Beet, red *(Beta vulgaris)*[5]	4.0	2.7	5.1	3.4	6.8	4.5	9.6	6.4	15	10
Squash, scallop *(Cucurbita pepo melopepo)*	3.2	2.1	3.8	2.6	4.8	3.2	6.3	4.2	9.4	6.3
Broccoli *(Brassica oleracea botrytis)*	2.8	1.9	3.9	2.6	5.5	3.7	8.2	5.5	14	9.1
Tomato *(Lycopersicon esculentum)*	2.5	1.7	3.5	2.3	5.0	3.4	7.6	5.0	13	8.4
Cucumber *(Cucumis sativus)*	2.5	1.7	3.3	2.2	4.4	2.9	6.3	4.2	10	6.8
Spinach *(Spinacia oleracea)*	2.0	1.3	3.3	2.2	5.3	3.5	8.6	5.7	15	10
Celery *(Apium graveolens)*	1.8	1.2	3.4	2.3	5.8	3.9	9.9	6.6	18	12
Cabbage *(Brassica oleracea capitata)*	1.8	1.2	2.8	1.9	4.4	2.9	7.0	4.6	12	8.1
Potato *(Solanum tuberosum)*	1.7	1.1	2.5	1.7	3.8	2.5	5.9	3.9	10	6.7
Corn, sweet (maize) *(Zea mays)*	1.7	1.1	2.5	1.7	3.8	2.5	5.9	3.9	10	6.7
Sweet potato *(Ipomoea batatas)*	1.5	1.0	2.4	1.6	3.8	2.5	6.0	4.0	11	7.1
Pepper *(Capsicum annuum)*	1.5	1.0	2.2	1.5	3.3	2.2	5.1	3.4	8.6	5.8
Lettuce *(Lactuca sativa)*	1.3	0.9	2.1	1.4	3.2	2.1	5.1	3.4	9.0	6.0
Radish *(Raphanus sativus)*	1.2	0.8	2.0	1.3	3.1	2.1	5.0	3.4	8.9	5.9

	100%		90%		75%		50%		0% "maximum"[3]	
	EC_e	EC_w	EC_e	EC_w	EC_e	EC_w	EC_e	EC_w	EC_e	EC_w
Onion *(Allium cepa)*	1.2	0.8	1.8	1.2	2.8	1.8	4.3	2.9	7.4	5.0
Carrot *(Daucus carota)*	1.0	0.7	1.7	1.1	2.8	1.9	4.6	3.0	8.1	5.4
Bean *(Phaseolus vulgaris)*	1.0	0.7	1.5	1.0	2.3	1.5	3.6	2.4	6.3	4.2
Turnip *(Brassica rapa)*	0.9	0.6	2.0	1.3	3.7	2.5	6.5	4.3	12	8.0
Wheatgrass, tall *(Agropyron elongatum)*	7.5	5.0	9.9	6.6	13	9.0	19	13	31	21
Wheatgrass, fairway crested *(Agropyron cristatum)*	7.5	5.0	9.0	6.0	11	7.4	15	9.8	22	15
Bermuda grass *(Cynodon dactylon)*[7]	6.9	4.6	8.5	5.6	11	7.2	15	9.8	23	15
Barley (forage) *(Hordeum vulgare)*[4]	6.0	4.0	7.4	4.9	9.5	6.4	13	8.7	20	13
Ryegrass, perennial *(Lolium perenne)*	5.6	3.7	6.9	4.6	8.9	5.9	12	8.1	19	13
Trefoil, narrowleaf birdsfoot[8] *(Lotus corniculatus tenuifolium)*	5.0	3.3	6.0	4.0	7.5	5.0	10	6.7	15	10
Harding grass *(Phalaris tuberosa)*	4.6	3.1	5.9	3.9	7.9	5.3	11	7.4	18	12
Fescue, tall *(Festuca elatior)*	3.9	2.6	5.5	3.6	7.8	5.2	12	7.8	20	13
Wheatgrass, standard crested *(Agropyron sibiricum)*	3.5	2.3	6.0	4.0	9.8	6.5	16	11	28	19
Vetch, common *(Vicia angustifolia)*	3.0	2.0	3.9	2.6	5.3	3.5	7.6	5.0	12	8.1
Sudan grass *(Sorghum sudanense)*	2.8	1.9	5.1	3.4	8.6	5.7	14	9.6	26	17
Wildrye, beardless *(Elymus triticoides)*	2.7	1.8	4.4	2.9	6.9	4.6	11	7.4	19	13
Cowpea (forage) *(Vigna unguiculata)*	2.5	1.7	3.4	2.3	4.8	3.2	7.1	4.8	12	7.8
Trefoil, big *(Lotus uliginosus)*	2.3	1.5	2.8	1.9	3.6	2.4	4.9	3.3	7.6	5.0
Sesbania *(Sesbania exaltata)*	2.3	1.5	3.7	2.5	5.9	3.9	9.4	6.3	17	11
Sphaerophysa *(Sphaerophysa salsula)*	2.2	1.5	3.6	2.4	5.8	3.8	9.3	6.2	16	11
Alfalfa *(Medicago sativa)*	2.0	1.3	3.4	2.2	5.4	3.6	8.8	5.9	16	10
Lovegrass *(Eragrostis sp.)*[9]	2.0	1.3	3.2	2.1	5.0	3.3	8.0	5.3	14	9.3
Corn (forage) (maize) *(Zea mays)*	1.8	1.2	3.2	2.1	5.2	3.5	8.6	5.7	15	10
Clover, berseem *(Trifolium alexandrinum)*	1.5	1.0	3.2	2.2	5.9	3.9	10	6.8	19	13
Orchard grass *(Dactylis glomerata)*	1.5	1.0	3.1	2.1	5.5	3.7	9.6	6.4	18	12
Foxtail, meadow *(Alopecurus pratensis)*	1.5	1.0	2.5	1.7	4.1	2.7	6.7	4.5	12	7.9
Clover, red *(Trifolium pratense)*	1.5	1.0	2.3	1.6	3.6	2.4	5.7	3.8	9.8	6.6
Clover, alsike *(Trifolium hybridum)*	1.5	1.0	2.3	1.6	3.6	2.4	5.7	3.8	9.8	6.6
Clover, ladino *(Trifolium repens)*	1.5	1.0	2.3	1.6	3.6	2.4	5.7	3.8	9.8	6.6
Clover, strawberry *(Trifolium fragiferum)*	1.5	1.0	2.3	1.6	3.6	2.4	5.7	3.8	9.8	6.6
Fruit crops[10]										
Date palm *(phoenix dactylifera)*	4.0	2.7	6.8	4.5	11	7.3	18	12	32	21
Grapefruit *(Citrus paradisi)*[11]	1.8	1.2	2.4	1.6	3.4	2.2	4.9	3.3	8.0	5.4
Orange *(Citrus sinensis)*	1.7	1.1	2.3	1.6	3.3	2.2	4.8	3.2	8.0	5.3
Peach *(Prunus persica)*	1.7	1.1	2.2	1.5	2.9	1.9	4.1	2.7	6.5	4.3

	100%		90%		75%		50%		0% "maximum"[3]	
	EC_e	EC_w	EC_e	EC_w	EC_e	EC_w	EC_e	EC_w	EC_e	EC_w
Apricot *(Prunus armeniaca)*[11]	1.6	1.1	2.0	1.3	2.6	1.8	3.7	2.5	5.8	3.8
Grape *(Vitus sp.)*[11]	1.5	1.0	2.5	1.7	4.1	2.7	6.7	4.5	12	7.9
Almond *(Prunus dulcis)*[11]	1.5	1.0	2.0	1.4	2.8	1.9	4.1	2.8	6.8	4.5
Plum, prune *(Prunus domestica)*[11]	1.5	1.0	2.1	1.4	2.9	1.9	4.3	2.9	7.1	4.7
Blackberry *(Rubus sp.)*	1.5	1.0	2.0	1.3	2.6	1.8	3.8	2.5	6.0	4.0
Boysenberry *(Rubus ursinus)*	1.5	1.0	2.0	1.3	2.6	1.8	3.8	2.5	6.0	4.0
Strawberry *(Fragaria sp.)*	1.0	0.7	1.3	0.9	1.8	1.2	2.5	1.7	4	2.7

[1] Adapted from Maas and Hoffman (1977) and Maas (1984). These data should only serve as a guide to relative tolerances among crops. Absolute tolerances vary depending upon climate, soil conditions and cultural practices. In gypsiferous soils, plants will tolerate about 2 dS/m higher soil salinity (ECe) than indicated but the water salinity (ECw) will remain the same as shown in this table.

[2] ECe means average root zone salinity as measured by electrical conductivity of the saturation extract of the soil, reported in deciSiemens per meter (dS/m) at 25°C. ECw means electrical conductivity of the irrigation water in deciSiemens per meter (dS/m). The relationship between soil salinity and water salinity (ECe = 1.5 ECw) assumes a 15–20 percent leaching fraction and a 40-30-20-10 percent water use pattern for the upper to lower quarters of the root zone. These assumptions were used in developing the guidelines in Table 1.

[3] The zero yield potential or maximum ECe indicates the theoretical soil salinity (ECe) atwhich crop growth ceases.

[4] Barley and wheat are less tolerant during their germination and seeding stage; ECe should not exceed 4–5 dS/m in the upper soil during this period.

[5] Beets are more sensitive during germination; ECe should not exceed 3 dS/m in the seeding area for garden beets and sugar beets.

[6] Semi-dwarf, short cultivars may be less tolerant.

[7] Tolerance given is an average of several varieties; Suwannee and Coastal Bermuda grass are about 20 percent more tolerant, while Common and Greenfield Bermuda grass are about 20percent less tolerant.

[8] Broadleaf Birdsfoot Trefoil seems less tolerant than Narrowleaf Birdsfoot Trefoil.

[9] Tolerance given is an average for Boer, Wilman, Sand and Weeping Lovegrass; Lehman Lovegrass seems about 50 percent more tolerant.

[10] These data are applicable when rootstocks are used that do not accumulate Na^+ and Cl^- rapidly or when these ions do not predominate in the soil. If either ions do, refer to the toxicity discussion in Section 4.

[11] Tolerance evaluation is based on tree growth and not on yield.

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Appendix E. Metrics Considered but Not Included in Proposed Methodology

The following methods were considered but not included in the report:

- Root Zone Moisture Management. Ration of the soil moisture to applied water.
- Effective Irrigation Efficiency. Ratio of crop ETAW to applied water minus agronomic and environmental use.
- Regional delivery fraction. Ratio of regional farm-gate delivery to total water diverted into the region.

The following indicators were considered but not included:

- Average Net Returns to Water is the value of output minus all non-water costs, divided by applied water. This is an average condition, so a higher average net return to water does not necessarily imply greater economic efficiency. Depending on the mix of data sources used, the calculations could produce negative net returns for some crops. Also, this calculation imputes to water the value of other inputs that are not explicitly priced, notably management.
- Marginal Value of Water for Agricultural Production. Statistical analysis and models can be used to estimate the Marginal Value of Water for Agricultural Production, using observed market information and behavior.

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Appendix F. Glossary

Agricultural Water Management Council – A non-profit organization established in 1996 dedicated to bringing together all interested parties in agricultural water management with the expressed goal to achieve greater water management efficiency. See: http://www.agwatercouncil.org/

Agricultural Water Management Plans (AWMPs) – Per SB X7-7, agricultural water suppliers that irrigate greater than or equal to 25,000 acres must complete a plan pursuant to CWC 10820 (see Appendix A).

Agronomic water use fraction (AWUF) – Method expands on the CCUF by including water for crop agronomic use at the basin, supplier or field scale. AWUF = (ETAW+AU)/AW.

Applied water (AW) – Consists of surface water diversions and /or surface water or groundwater deliveries to a boundary (field, water supplier or basin) excluding municipal and industrial uses.

California Water Code – Statutes adopted by the Legislature.
See: http://www.leginfo.ca.gov/cgi-bin/calawquery?codesection=wat

California Water Plan (CWP) – collaborative planning framework for elected officials, agencies, tribes, water and resource managers, businesses, academia, stakeholders, and the public to develop findings and recommendations and make informed decisions for California's water future. The plan, updated every 5 years, presents the status and trends of California's water-dependent natural resources; water supplies; and agricultural, urban, and environmental water demands for a range of plausible future scenarios.
See: http://www.waterplan.water.ca.gov/

Consumptive use – refers to water that is unavailable for reuse in the basin from which it was extracted, e.g., soil evaporation, plant transpiration, incorporation into plant biomass seepage to a saline sink, or by contamination.

Crop consumptive use fraction (CCUF) – Method that evaluates the relationship between the consumptive use of a crop and the quantity of water applied for that purpose at the basin, supplier, or field scale. CCUF=ETAW/[AW]

Crop evapotranspiration – water that enters the atmosphere by the combined processes of evaporation from crop and soil surfaces and transpiration from crops.

Delivery fraction (DF) – Indicator evaluates the relationship between the water delivered to an area and the total applied surface or groundwater at the supplier scale. DF = FGD/WS

Detailed analysis unit (DAU) – From 1974 to date, DAUs have been delineated statewide and used as part of statewide planning and focused to accommodate county statistics. See http://www.waterplan.water.ca.gov/docs/maps/dau-web.pdf

Distribution uniformity (DU) – Indicator evaluates the performance and effectiveness of an irrigation system at the field scale. DU = Dawlq/Daw

Effective precipitation (Pe) – fraction of precipitation water that is available for crops to use.

Environmental use (EU) – portion of applied water directed to environmental purposes within a defined scale that is not meeting ETAW of the irrigated commodity including such uses as water to produce and/or maintain wetlands, riparian or terrestrial habitats, where the quantity of water consumed or used for intended objectives is based on accepted professional practices.

Evapotranspiration (ET) – is a term used to describe the sum of evaporation and plant transpiration from the Earth's land surface to atmosphere. Evaporation accounts for the movement of water to the air from sources such as the soil and canopy interception. Transpiration accounts for the movement of water within a plant and the subsequent loss of water as vapor through stomata in its leaves.

Evapotranspiration of applied water (ETAW) – crop evapotranspiration minus the amount of water supplied to the crop by precipitation.

Farm-gate delivery (FGD) – the water delivery by the water supplier to its customer at the farm-gate.

Field scale – a term used to define the boundary of a parcel(s) of land served by an irrigation method or system.

Hydrologic – Pertaining to the circulation, distribution, and use of water.

Leaching – the practice of applying required amount of water as a part of irrigation to avoid salts from building up in the soil.

Mobile labs – mobile irrigation laboratories consisting of team of technicians and equipments to evaluate the performance of irrigation systems. The laboratories measure water application rates and system distribution uniformity and give recommendations for irrigation system improvement, if necessary.

Non-consumptive use – refers to water that is available for reuse within the basin from which it was extracted, e.g., through return flows.

Productivity of Applied Water (PAW) – Indicator illustrates the relationship between crop production in tonnage and the volume of applied water at the statewide, county or field scale. PAW = CY/AW

Recoverable flows – consist of the amount of water leaving a given area as surface flows to non-saline bodies or percolation to usable groundwater and is available for supply or reuse.

Riparian – A riparian zone or riparian area is the interface between land and a river or stream.

Saline sink – a salt covered depression or a terminal point for discharge and disposition of water or other materials.

Tailwater – the spill water from the water supplier distribution system or water flowing out of the end of an irrigated field.

Tilewater - the drainage water collected by on-farm drainage systems.

Total water use fraction (TWUF) – Method expands on the CCUF by including water for crop agronomic use and to meet environmental objectives at the basin, supplier or field scale. TWUF = (ETAW+AU+EU)/AW

Transpiration – It is a part of the water cycle, and it is the loss of water vapor from parts of plants, especially in leaves but also in stems, flowers and roots.

U.S. Department of Agriculture National Agricultural Statistics Service (USDA NASS) – conducts hundreds of surveys every year and prepares reports covering U.S. agriculture. Production and supplies of food and fiber, prices paid and received by farmers, farm labor and wages, farm finances, chemical use, and changes in the demographics of U.S. producers are only a few examples (http://www.nass.usda.gov/).

Value of Applied Water (VAW) – Indicator illustrates the relationship between gross crop revenue in dollars and the volume of applied water at the statewide, county scale. VAW = GCR/AW

Water balance – a representation of all sources and dispositions of water into, within, and out of a defined boundary over a defined period of time.

Water management fraction (WMF) – Method evaluates the recoverable water available for reuse at another place or time in the system at the basin or supplier scale. WMF = (ETAW+ RF)/AW

Water supplier scale – a term used to define a boundary of agricultural irrigated land, either publicly or privately owned, that distributes or sells water for ultimate resale to customers.

Water use efficiency method – water use efficiency fractions that indicate a ratio of beneficial output from an agricultural system to an input to the agricultural system in volumes and/or depths of water and are considered for quantifying the efficiency of agricultural water use.